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Raymond Joseph Nadeau

Date of Birth — Date de naissance

October 6, 1925

Country of Birth — Lieu de naissance

Canada

Permanent Address — Résidence fixe

Box 52 Barrhead, Alberta

Title of Thesis — Titre de la thèse

Inquiry Teaching in the Chemistry Laboratory

University — Université

ALBERTA

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1984

Name of Supervisor — Nom du directeur de thèse

Dr Marshall Nay

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INQUIRY TEACHING IN THE CHEMISTRY LABORATORY

by

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RAYMOND JOSEPH NADEAU

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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M. A. Nay

Supervisor

V. R. Nyberg

Date February 2, 1984

DEDICATION

This thesis is dedicated

to my wife

Margaret

for her unfailing faith and

long-lasting patience

ABSTRACT

The purpose of this study was to determine to what extent students were able to attain inquiry objectives while performing specially designed experiments in the chemistry laboratory. The subjective meanings that students had regarding this type of learning was also determined. The laboratory program was conducted with a class of 20 grade twelve chemistry students during an entire semester.

By means of eleven carefully designed experiments, the amount of structuring of the learning and the amount of guidance provided by the teacher were gradually reduced. The reduction in structure produced an increase in the level of inquiry learning and teaching of the existing laboratory curriculum of chemistry 30, a senior high school science subject prescribed by Alberta Education.

The testing instruments used to gather data for the formative and summative evaluations were: Chemistry 30 Achievement Examination, Processes of Science Test, Test on Scientific Attitudes, Laboratory Questionnaires, Students Written Comments, Taped Interviews, Laboratory Reports, and Teacher's Log.

Behavioral objectives in the conceptual, affective and scientific process skill domains were measured by means of two paradigms--the empirical analytic and the situational interpretative. The di-paradigmatic approach measured student behavior and achievement not only before and after but throughout the inquiry-oriented laboratory program.

Although students of this study spent considerably more time in the science laboratory and with laboratory related activities than students of a regular chemistry curriculum, they were able to perform as well on the Alberta Education Achievement Test. Students also scored considerably higher at the end of the semester than at the beginning on the process skill domain test but did not show significant growth on the test for scientific attitudes. A significant majority of students expressed that they found the laboratory program not only challenging, interesting and enjoyable but that the type of inquiry experiments of this study was preferable to the highly structured experiments preformed in previous years.

The multi-faceted evaluation of the laboratory program revealed that students were able to perform the necessary process skills required by the teaching strategies of this study. The results from both paradigms showed that inquiry-oriented learning and teaching based on the scientific process skills is a viable objective at the high school chemistry level. By systematically reducing guidance from the teacher and decreasing the number of instructional aids, students can learn to perform high level inquiry activities.

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CHAPTER 1

THE PROBLEM

The search for a universal generalization on a proper teaching strategy and the search for a simple solution to all major educational problems are pursuits which are probably fruitless. The first undoubtedly does not exist while the second is much too simple. The aim of the majority of educational studies on instruction, according to Okey (1971), is to establish a limited generalization about a specific teaching strategy. He describes a limited generalization as a determination of conditions, instructional materials, and procedures to facilitate attainment of objectives. (1970, p. 285)

Background to the Problem

The aim of this study is to establish a generalization concerning the use of the laboratory in teaching science. The variable condition is the degree of structure or guidance given to each laboratory experiment in the prescribed core of the Alberta high school chemistry course, ALCHEM 30 (Alberta Education, 1977).

The science disciplines at the high school level have always had laboratory work as an integral part of the curriculum; however, the time currently stipulated for the laboratory work has reached a record high in Alberta. The trend started at the beginning of the space age with 'sputnik' and was quickly followed by the appearance of major science programs (BSCS, CBA, CHEMS, PSSC, Nuffield Sciences, etc.). These original programs, designed to have the student behave like a scientist in the laboratory, have disappeared or changed since the 1960's but the intents regarding the laboratory work, at least in Alberta, have not. The present curriculum guide for senior high school chemistry states that "...it is a common practice to devote approximately 40 per cent of the class time to laboratory activities." (Alberta Education, 1977, p. 10). However, some questions need to be asked about the intended quality and effectiveness of the laboratory experience in chemistry.

Inquiry and ALCHEM 30

The salient objectives regarding laboratory work in chemistry, cited below, are to be found in the Program of Studies for Senior High Schools of Alberta (Alberta Education, pp. 1-4):

4. To promote understanding of and development of skill in the methods used by scientists:
    a. processes in scientific inquiry such as observing, hypothesizing, classifying, experimenting and interpreting data
    b. intellectual abilities such as intuition, rational thinking, creativity, and critical thinking
    c. skills such as manipulation of materials, communication, solving problems in groups, and leadership.

5. To promote assimilation of scientific knowledge:

   e. open-endedness of science and the tentativeness of scientific knowledge

6. To develop attitudes, interests, values and appreciations, and adjustments similar to those exhibited by scientists at work.

Two objectives restated for high school chemistry are:

1.1 processes in scientific inquiry: observing, hypothesizing, classifying, experimenting and interpreting data.

1.2 skills in the cognitive, affective, and psychomoter domains.

1.3 skills in individual and group problem solving.

How does the ALCHEM 30 program attain these stated objectives of the high school chemistry curriculum guide?

ALCHEM 30, a curriculum employing applied and descriptive chemistry, integrates textual materials, laboratory activities, demonstrations, and classroom exercises. The inquiry approach, advocated by the Alberta program of studies and by almost every science curriculum today, is not mentioned in the preface of the ALCHEM materials. The laboratory experiments, with few exceptions, are essentially of the deductive variety. They are lessons designed mainly for purposes of illustration and verification; the student by carefully following the field-tested procedures can obtain reasonably good illustrative or confirmatory results. The ALCHEM 30 materials require that the student, by means of pre-laboratory discussions and individual study, comes to the laboratory with some degree of understanding about the problem under discussion. However, not only is the problem given to the student in the laboratory manual but he is also given detailed procedural steps and methods to analyze and process the data. This type of activity in the laboratory is not classified as inquiry according to Schwab; "...the appearance but not the reality of inquiry is provided." (Schwab, 1964, p. 55).

The desired learning outcomes of a laboratory science program, be they the acquisition of facts, concepts, theories, or skills, are obtained through processes--the scientific processes of inquiry. But inquiry as a mode of learning in the laboratory is concerned with how a student goes about his determinations rather than with what determinations are made or how accurately they are made. The thought patterns are seen to be as important, if not more so, than the knowledge itself.

In the deductive laboratory the student follows explicit directions for collecting and processing data according to a plan, that which is stated in the laboratory manuals. These activities are especially appropriate for students with little or few laboratory skills. They are also important for students who require hands-on experiences to help make concepts more significant. Schwab (1964) however, perceives these activities as only prerequisites to inquiry. Nay (1970, p. 22), on the other hand, sees them as inquiry but of a low level type.

The ALCHEM 30 laboratory experiments provide students with the opportunity of practicing skills such as measurements of mass, volume, density, etc. The experiments also acquaint students with the use of graduate cylinders, burets, pipets, calorimeters, voltmeters, pH meters, etc. Concepts such as percent error, limitation of measuring instruments, dimensional analysis, etc. are also presented to the student. Nevertheless, inquiry, if defined in terms of scientific process skills, demands that the above skills be initiated and developed by the students as well as being practiced. Of course, the student needs to be shown how to perform specific acts necessary in executing a laboratory skill, and he will have to acquire a certain degree of expertise in that skill; but in an inquiry lesson the laboratory manual should not provide the student with explicit directions of which skills he is to use nor when he is to use them. These ought to be the student's responsibility to a greater or lesser degree depending upon the prevailing circumstances. Otherwise, the student is only practising the skills of process. He is not initiating and developing them.

The student participating in an inquiry laboratory is operating before, during and after the laboratory period at a higher cognitive level: seeking background information, hypothesizing, designing the collection of data, identifying the limitations of design, modifying procedures, repeating the experiment, using trial and error, recognizing failures and limitations, describing, tabulating, recording, processing, judging, interpreting, formulating, and so on. These are processes of scientific inquiry and the essence of learning science by inquiry as defined in Biological Sciences Curriculum Study (BSCS), Science-A Process Approach, and other curriculum projects.

In the light of the above discussion it must be concluded that using only ALCHEM 30 materials and its implied strategies, many of the objectives cited in the curriculum guide with reference to the laboratory work are difficult to attain unless the teacher makes appropriate modifications on the basis of an acceptable rationale.

The dilemma of trying to attain the educational objectives regarding the scientific process skills and inquiry teaching was perhaps the main reason for this study. Educational objectives have many functions, but according to Taba

> ...perhaps the most important one is that of guiding decisions about the selection of content and of learning experiences and of providing criteria on what to teach and how to teach it. ...No matter what its nature, the statement of desired outcomes sets the scope and the limits for what is to be taught and learned. (Taba, 1962, p. 197)

This ends-means rationale initially prompted the undertaking of this study.

Implications for Science Teaching

Why is it so important to have students design their own experimental steps, organize and tabulate their own data, and process results in their own way? The teaching strategy of this study rests on the assumption that these activities, which are the foundation of most problem solving strategies, are important ones for students to exhibit.

To say that these activities, the scientific process skills, are important, is to agree with the experts, the curriculum theorists, who state that these activities are the activities that scientists engage in and, therefore, are worthwhile activities to learn. The experts also claim that students will "learn how to learn." These claims require further elucidation.

The experiences of the laboratory work in the science curriculum are probably closer to the real world of science for the student than any other experience. However, the bits and pieces of the activities must fit together in such a way that the experiences are relevant and meaningful for the student. To be told precisely how to perform and process an experiment does not mean that students will necessarily learn how to use the scientific process skills or that they will learn how knowledge is acquired. They are not experiencing the proper activities, and to go on repeating the exercise will probably not help, regardless of the number of times it is repeated. A student completing the present ALCHEM program (10 20, and 30 sequence) will perform over twenty such experiments. Schwab, disclaiming such activities in the science classroom, says

> On the one hand, there is a growing tendency to escape the diversities of enquiry by conceiving it as primarily a matter of simple "controlled experiment," of precision, and of technical proficiency. Under the sway of this false simplicity, many science classrooms are being converted into research microcosms in which every high school student, regardless of interest and competence, is supposed to act, on a small scale, like a scientist. He is required to master techniques and to collect data. But the intellectual problem of interpreting these data is avoided and the problem under enquiry is treated as something given. Meanwhile the textbook [laboratory manual] continues to be a rhetoric of conclusions and the end result is little nearer the mark of the teaching of science as enquiry than our former habits. (Schwab, 1964, p. 102)

The situation in the Alberta classroom today, nearly twenty years later, has apparently changed very little. If the activities that scientists engage in are considered worthwhile to learn (Schwab, 1964, pp. 73, 96, 102), then the important questions to consider become whether the activities can indeed be experienced by high school students and, if so, to what degree. Furthermore, if students experience the activities, what is it that they learn from them?

The activites of this study are suggested by theory, particularly by Schwab (1964, p. 55) and his levels of inquiry. In practice this theory perhaps may prove not to be the best way to learn the scientific process skills. The higher level inquiry laboratory exercises may require an inordinate amount of classroom time and not permit other objectives in the discipline to be realized. This teaching strategy may be inappropriate for students at this age level. Perhaps these activities should only be carried out at the university level where materials, resources and teacher expertise are available to a greater degree. Or, the use of these activities at the high school level may be "perverted." Schwab suggests that

> The use of scholarly material as a resource for curriculum can be perverted, ... Perversion consists of warping the scholarly material out of their character in order to force them to serve a curricular purpose which fascinates the planners. (Schwab, 1973, p. 377)

In the opinion of the investigator of this study the curriculum developers of the ALCHEM series have provided far too few of the process skills under discussion in their laboratory exercises. Process skills for the original experiments and the revised experiments are displayed by means of a grid in Appendix A.

For the reasons stated, this study, a teacher study, should be undertaken; and judging from the insignificant numbers of studies of this type of "action research" endeavors of this kind are overdue. There have been too few studies stressing the practical side of educational research. Schubert, believing that the theoretical orientation is the dominant one in education today rather than the practical one, concludes by saying:

> Finally, practitioners and scholars must inquire together to discover research modes that must productively serve the massive problems confronting the daily flow of students into the schools. (Schubert, 1980)

Introduction to the Problem

The present evaluation methods used in the science laboratory are relatively rudimentary and limiting, and the majority of tests used in science are concerned primarily with the knowledge and comprehension levels of behavior identified in Bloom's Taxonomy of Education Objectives, Handbook I: Cognitive Domain (1956).

By employing in the laboratory a somewhat different strategy than the one suggested in ALCHEM 30, the author of this study hopes to determine whether unstructured laboratory experiments can provide experiences for students that have a greater opportunity to develop the higher level type of cognitive skills.

Pupils' attitudes and feelings for this type of teaching strategy are also sought: Do students welcome the challenge of design and processing? Are the requirements too difficult? Do students enjoy this type of laboratory experience as much as the the conventional type? How will this type of inquiry teaching affect the students' attitudes toward science as a discipline? How will it affect attitudes toward learning?

Statement of the Problem

The purpose of this study is three-fold:

1. To determine the manner and extent to which students who are presented with laboratory experiences which are minimally structured are able to attain the objectives in the conceptual (higher level), affective, and scientific process skill domains.
2. To determine how students "feel" about learning chemistry by inquiry: the subjective meanings that students attach to their own behavior regarding this type of inquiry learning.
3. To determine whether an inquiry oriented laboratory program enhances student performance in the utilization of scientific process skills and in the understanding of scientific attitudes.

Other purposes of the study are embodied in the following questions:

1. What, if any, is the consequence on concept development of spending the additional time required on inquiry laboratory exercises?
2. What is the relationship between performance on paper-and-pencil tests and laboratory reporting?
3. How does the evaluation obtained from the empirical-analytic research paradigm relate to that obtained from the interpretative-situational one?
4. What specific strategies must be employed by the classroom teacher to teach the chemistry laboratory by inquiry?
5. Do the strategies of this study provide a practical way of teaching scientific process skills and developing scientific attitudes?

Research Design

In order to determine the manner and extent to which students attain objectives in the three domains (conceptual, affective and scientific process skill) a di-paradigmatic approach was used. Quantitative data, collected from several testing instruments (content exam, process skill test, attitude test, and laboratory reports), were analyzed by the conventional empirical-analytic paradigm. Qualitative data from such instruments as questionnaires, written statements, taped interviews, and a teacher's log were analyzed by means of the situational-interpretative paradigm.

The effectiveness of the inquiry teaching strategies used in this study was first assessed during two pilot programs which preceded the main study. The evaluation of the data collected from the pilots indicated that students achieved some of the stated objectives in all three domains. The main study evolved into its present form from refinements of testing instruments and data gathering techniques of the pilots. The qualitative data were collected to determine how students felt about the laboratory program. Most of the data collected in the study were gathered to determine the meanings, the intents, and the attitudes that students had toward the laboratory program. Too often students are not consulted about how they feel about a new program.

Definition of Key Terms

1. ALCHEM 30. This science subject is a high school chemistry course at the grade twelve level consisting of three units which comprise the core: chemical energetics, oxidation-reduction, and acids and bases. Student laboratory experiments, exercises, demonstrations, and textual materials are integrated in the applied and descriptive chemistry content. The laboratory experiments provide students with detailed procedural steps, set-ups of apparatus, directions for

collecting data, and methods for treating data.

2. Revised ALCHEM 30 Experiments. The eight experiments in ALCHEM 30 have all been revised and the number has been extended to 11 experiments. Students are required in the revised experiments to design experimental steps, provide set-ups of apparatus, tabulate observations and interpret data in their own way. These skills are initiated by the student in the revised experiments whereas in ALCHEM 30 directions are provided. See Appendix B.

3. Scientific Process Skills. These are the activities that scientists engage in while attempting to understand nature. They are many and complex. For purposes of this study, the activities, analyzed into simpler behaviors, are those identified in An Inventory of Processes in Scientific Inquiry by Nay and Associates (1971). The inventory is based on Science -- A Process Approach (Gagne, 1965), Schwab's theory on the structure of the disciplines and his meaning of inquiry (1964), and Nay's own perception of the nature of science and science teaching. (See Appendix C). The Inventory is used as the basis for defining objectives in the process domain. There are two aspects to these objectives: one which involves students knowing the processes of scientific inquiry (cognition) and the other which

requires students to use them while solving problems (action).

4. Inquiry Approach to Teaching Science. With reference to this study the notion of inquiry teaching in the laboratory is based on Schwab's concept of teaching science (1964). He insists that students are able to learn science by inquiry which he describes as a series of strategies and processes not divorced from content. The inquiring laboratory serves two functions: (1) "to provide a tangible experience of some of the problems dealt with and of the difficulty of acquiring data." (2) The laboratory manual "ceases to be a volume which tells the student what to do and what to expect." (1964, p. 55). Inquiry, particularly Schwab's more recent views, are discussed further in Chapter II.
5. Levels of Inquiry. The level of inquiry, for purposes of this study, increases as the amount of structuring (direction and guidance) provided by the laboratory manual and the teacher decreases. Schwab (1964) describes three levels of inquiry in the laboratory. In his third and highest level of inquiry, for example, the "problem, as well as answer and method, are left open: the student is confronted with the raw phenomenon." (1964, p. 55). Nay (1970) describes the directions given to the student at each level of inquiry in terms

of scientific process skills, and he includes the "cook-book" type of experiment (highly structured) as the lowest level of inquiry while the highest level has the greatest amount of self-direction and creativity on the part of the student. (See Appendix D).

6. Affective Domain. The affective domain refers to the set of objectives in An Inventory of Affective Attributes of Scientists (Nay and Crocker, 1970, pp. 61-62). The objectives are classified as interests, operational adjustments, intellectual adjustments or attitudes, appreciations and values. See Appendix E.
7. Attitude Domain. This area is a subset of the affective domain. On the one hand it refers to the attitudes and personal feelings that students have toward their participation in the laboratory program. To determine these feelings is a major purpose of the study. On the other hand it refers to scientific attitudes. These arise from the intellectual adjustments in the inventory by Nay and Crocker (1970) and are the intellectual behaviors which are foundational to the scientist's contribution to or acceptance of new scientific knowledge. Kozlow and Nay (1976) identify three components for each of the behavioral objectives under the attitudes in the inventory: cognition, intent, and action. The cognition component deals with knowing and

understanding how attitudes manifest themselves in the professional behavior of scientists. The intent component deals with approval or disapproval by students of behaviors which define an attitude. The action component represents to what extent behaviors, which define an attitude, are demonstrated by students (Kozlow and Nay, 1976, pp. 149-150).

8. Concept Domain. For the purposes of this study this refers primarily to the chemistry content in ALCHEM. How students are able to deal with this content will be measured in terms of Bloom's Taxonomy which "includes those objectives which deal with the recall or recognition of knowledge and the development of intellectual abilities and skills." (Bloom, 1956).
9. Processes of Science Test (POST). The important scientific process skills measured by this test are indicated in Appendix F.
10. Test on Scientific Attitude (TOSA). Regarding this study, TOSA measures (a) the student's understanding of how scientists behave attitudinally while doing research and (b) the student's intended attitude behavior in such scientific attitudes as objectivity, open-mindedness, and critical mindedness. See Appendix G.
11. Evaluation Paradigm. The term paradigm, in this study, refers to a conceptual model, a perspective (Kuhn,

1970). Two evaluation perspectives are used in this study: empirical-analytic and situational-interpretative. These paradigms have their definitions in the works of Habermas (1971) and have been adopted by Aoki (1978, 1980) and others in curriculum development and evaluation. The empirical-analytic is the conventional test-based paradigm used in educational research and often called technical or normative. The situational-interpretative paradigm, in this study, is concerned with the meanings that students in a laboratory classroom, assume and bring to the social setting. It is a way of breaking down the "complex nature of reality" (Patton, 1975).

Delimitations and Limitations

1. In the empirical analytic paradigm, this study is delimited to three quantitative measuring instruments: Chemistry 30 Achievement Test (Chem 30 Test), Process of Science Test (POST), and Test on Scientific Attitudes (TOSA). These tests have their own imposed limitations and will be discussed in greater detail under Testing Instruments in Chapter 3. The results from the three quantitative instruments provide data only in the concept, scientific process skill and attitude domains respectively in relation to inquiry teaching.
2. In the situational-interpretative paradigm, this study

is delimited to four data gathering instruments: questionnaires, written comments, taped interviews and the teacher's log. The teacher's log is a compiled record of salient student laboratory activities made by the teacher who is acting somewhat as a 'participant-observer.'

3. The study is confined to the laboratory component of the revised ALCHEM 30 experiments.
4. Caution should be exercised in generalizing the findings from this study because of the non-random sample used and the limited range of quantitative and qualitative data-gathering instruments.

CHAPTER 2

REVIEW OF THE LITERATURE

The review of the literature in this chapter attempts to show historically how researchers have viewed the role and the nature of the chemistry laboratory. Because the setting of the present investigation is a high school chemistry laboratory, views about the laboratory are considered of paramount importance. Sections adopted for this study and relevant to methods of evaluation by the empirical-analytic and the situational-interpretative paradigms follow the nature of the chemistry laboratory review.

Role of the Laboratory

The traditional role of the laboratory in the teaching of chemistry has been one of mainly providing the student with illustrations, demonstrations, and a place where principles and concepts can be verified. Blackboard chemistry and classroom work have always been supported by the laboratotory work; however, the traditional laboratory "emphasized what is known rather than how it is known, consequently the modes of inquiry of science received little attention" (Pawloff, 1974, p. 11, emphasis added).

As early as 1916 the progressive movement led by John Dewey advocated the investigative approach in science.

Later Dewey (1938) emphasized problem-solving and encouraged courses in "practical" science. And ever since, for nearly fifty years, the work of students in the laboratory has been criticized by educators: some have suggested that the laboratory is a waste of time while others have insisted the experiences are indispensable (Tamir, 1976).

In the 1960's the role of the laboratory was re-emphasized. Science educators insisted that the curriculum had to be "laboratory-centered rather than text or lecture-centered" (Romey, 1968, p. 20). Piaget (1964) and studies in developmental psychology showed that children needed concrete experiences in order to learn scientific concepts. Ausubel (1968) contended that older students encountering unfamiliar types of study required similar concrete experiences. Ramsey and Howe (1969) reviewing studies on laboratory experiences of the new curricula of the 1960's wrote:

> It has been, and indeed it is the trend in many of the course improvement projects, to make laboratory experiences central to instructional procedures in science, yet direct research on what these experiences should be, how they should be organized, and where they function best, is indeed meager. (1969, p. 76)

The authors of CHEM Study stated that "heavy reliance is placed upon laboratory work so that chemical principles can be drawn directly from student experiences." The laboratory work gives "maximum opportunity for discovery, the most exciting part of scientific activity." (Chemical Education Material Study, 1963, Foreward; Bates, 1978). This attitude, regarding laboratory work as a learning mode, has been supported by Smith et al (1968) and Cooper and Petrosky (1974). These studies showed that students selected laboratory work as the preferred instructional mode.

By the 1970's, the role of the laboratory in secondary school programs was considered a foregone conclusion. The Commission on Professional Standards and Practices of the National Science Teachers Association (NSTA, 1970) said, for example, "the time is surely past when science teachers must plead the case for school laboratories." (NSTA, 1970, p 3). Shulman and Tamir (1973) stated "With the advance of new curricula which stress the process of science and emphasize the development of higher cognitive skills, the laboratory has acquired a central role, not just as a place for demonstration and confirmation but rather as the core of the science learning process."

Today in the 1980's the situation, in the United States at least, appears to be changing. Because of the existing economic conditions, new austerity programs demand priorities, justifications, and restraints. And according to Bates (1977, p 56) science teachers are being required to "justify their requirements" for the laboratory. Recently, Alberta Education has been pressured to reinstate provincial wide examinations. Prior to 1973, the provincial Chemistry 30 examinations, then known as the "departmentals", seldom included questions on laboratory activities; and, coincidentally, it was rumored at the time, that some teachers actually taught the science course without including the laboratory experiments. Laboratory work, for some teachers, was not considered important. Yager, Engen and Snider (1969) found that some advanced level students claimed that the lab work was for them a waste of time. Bates (1978, p 72), on this issue, suggests that the background of the student may not be properly matched to "appropriate laboratory experiences." If the laboratory component of the science curriculum is to survive, it is imperative that research determine ways of evaluating what is happening in the laboratory and what it is that is worthwhile.

At present, the laboratory work still plays an integral role in the teaching of science in Alberta. In every science course (ALCHEM, Keys to Chemistry, Project Physics, BSCS, etc.) the laboratory is not only compulsory but in some programs it plays the dominant role. Student laboratories and demonstrations sometimes lead rather than supplement the classroom activities. For example, the first two experiments in ALCHEM 30 dealing with molar heat of a phase change and molar heat of a chemical change are sequenced early in the unit on Energy, and the classroom work is essentially a prelab discussion to help the student understand the concept of molar heats.

Investigating the role of the laboratory, Bates (1978, p 74) suggests the following tentative conclusions from current research:

1. Lecture, demonstration, and laboratory teaching methods appear equally effective in transmitting science content.
2. Laboratory experiences are superior for providing students skills in working with equipment.
3. Although most research has failed to assess outcomes that might be specific to the laboratory, meaningful laboratory measures can be developed; the laboratory appears to represent a significantly different area of science learning than content acquisition.
4. Some kinds of inquiry-oriented laboratory activities appear betterthan lecture/demonstration or verification labs for teaching the process of inquiry. However, teachers need to be skilled in inquiry teaching methods; specific inquiry training should be provided over extended periods; and students need both time and guidance to become comfortable with the new methods and expectations.
5. Laboratories appear to have potential for nurturing positive student attitudes and for providing a wider variety of students with opportunities to be successful in science.
6. Recent and continuing research on the role of science teaching for nurturing cognitive development may, in the relatively near future, provide important new science teaching strategies in which properly designed laboratory activities will have a central role.

The perspectives of this study are particularly pertinent to points 3, 4, 5, and 6 above and are attempts to determine, under controlled conditions, what is happening in a high school chemistry laboratory.

The Nature of Laboratory Work: Inquiry

As mentioned previously, the traditional role of the laboratory was to support the classroom science teaching by illustration and verification. Since the 1960's the role of the laboratory has steadily increased. This increase has brought about different teaching strategies: inquiry, discovery, problem solving, inductive teaching, etc. Schwab (1964) identifies these strategies by classifying them as levels of inquiry. At the first level (the simplest) the teacher or the manual poses the problem and describes the methods to be used by the student. The student, presumably, does not know the answer to the problem beforehand. At the second level, the problem is given but the methods and answers are not. While at the third level, the student is "confronted with the raw phenomenon." At this level problem, method, and solution are not given (Schwab, 1964, p 55).

The laboratory experiments in the Chemical Bond Approach Project (1963), Investigating Chemical Systems, are structured in a manner similar to Schwab's levels of inquiry. (This program was piloted in Alberta but because of its difficulty was never adopted.) Students performing Group I experiments in CBA are given considerable background information in order to plan the laboratory work and a great deal of help in the form of specific directions by the laboratory manual in actually doing the experiment. Group II experiments are more difficult. The student is given fewer directions to conduct the experiment and process the data. Finally, in Group III, the student is given very little help: the problems, which are more difficult than in Group I and Group II, resemble projects for independent study. Students reaching this level are encouraged to participate in designing experiments:

> At first the task of proposing a plan for conducting an investigation will be somewhat difficult for you. After you have participated in this type of activity several times, you will find that this phase of the laboratory work is challenging and rewarding. It is hoped that you will develop some ingenuity in the design of investigations. This will be especially important if you wish to undertake the investigation of any of the experiments included in Group III. (CBA Project, 1963, p 4)

In the present study some features of the CBA Project have been incorporated. The first experiment in each unit in the Revised ALCHEM 30 resembles the Group 1 type experiments in CBA while subsequent experiments resemble Group II and III from CBA. Another source which influenced the format of the written reports and the structure of the laboratory program for the Revised ALCHEM 30 experiments was the The Laboratory Structure and Task Analysis (LAI): A

Users' Handbook by Fuhrman, Lunetta, Novick, and Tamir (1976). The notion of high and low structure, the postlab discussion, and the categorization of levels of student designs and observations, all found in the Task Analysis Inventory, influenced the methodology that was finally adopted in this study.

Nay (1970) describes the laboratory exercises mentioned in CBA in terms of Schwab's levels of inquiry and emphasizes that the degree of structuring stated in the laboratory manual and the amount of guidance provided by the teacher influences the level of inquiry. The nature of the structuring and guidance is in terms of the processes of inquiry: initiation, collection of data, processing of data, conceptualization of data, and open-endedness (Appendix C). However, the level of inquiry teaching attained will depend upon the teacher, particularly his style and commitment. It will also depend upon pupil preparation and available resources (Nay, 1970, p 23). Nay's chart "Characterization of an Inquiry Lesson " (Appendix D) relates the degree of structure and guidance, level of inquiry, and teaching mode. The teaching strategy in this study based on Nay's premises is such that the structuring of the learning (from the lab manual) and guidance by the teacher are both gradually decreased within each unit and throughout the year.

Recent studies concerning laboratory activities have focused on such dimensions as: ability to generalize in new situations, ability to use the process skills specific to science, proficiency in the necessary process and psychomotor skills, student attitudes, and the process dimension of knowledge (Science Education Information Reports, 1979).

Recently Hofstein and Lunetta (1982, p 213) reviewing the role of the laboratory in science teaching insisted that "there was a real need to pursue vigorously research on learning through laboratory activities..." In their summary of the research they said:

> Appropriate laboratory activities can be effective in promoting logical development and the development of some inquiry and problem-solving skills. For example, they can assist in the development of manipulative and observational skills and in understanding scientific concepts. They also can promote positive attitudes, and they provide opportunities for student success and foster the development of skills in operation and communication. (1982, p 212)

Schwab (1964) agrees that process skills can be learned by the student outside of the laboratory. The study of case histories, advocated by Schwab, is included in Project Physics (1973); but the most opportune place to develop the process skills of scientific inquiry is in the laboratory (Powley, 1971, p 203). Furthermore, the development of the skills are best done with investigative type experiments rather than the verification approach.

Evaluating the Laboratory

The majority of studies about the laboratory, according to Bates (1977, p 63), have not focused on "instructional aims from the cognitive, affective, and psychomotor domains." Nevertheless, in reviewing the work of Shulman and Tamir (1973) Bates (1978, p 63) mentions that laboratory performance skills are now being evaluated and distinguished from science content acquistion. Klopfer (1971) has a Table of Specifics for evaluating science instruction which includes means to measure the effectiveness of the laboratory. Klopfer's objectives for the Process of Scientific Inquiry are similar to the model for this study: Nay's Inventory (Appendix C)

Laboratory objectives were first proposed by Mager (1962), Nedelsky (1965), Atkin (1968), Popham (1969), and others. Although not called such, these objectives were largely based on expected student behaviors. Nedelsky (1965) using the taxonomic approach outlined the following abilities: (a) dealing with knowledge, (b) understanding theory and phenomenon, etc., and (c) learning from experiment (laboratory skills, disciplined and imaginative thinking). Nedelsky's laboratory work, based on his objectives, produced laboratory experiments that were adopted by Chemical Bond Approach (1963).

Pawloff (1974), summarizing the effects of different laboratory techniques, found that although laboratory work plays an important role in the science curriculum, few studies here produced significant results. Different instructional techniques have had "little effect on the outcomes that we are presently able to measure." (Pawloff, 1974, p 72). In his reviews, Bates (1978, p 57) looking at outcomes that research seeks to measure and at the evaluation instruments used, is in agreement with Pawloff. As mentioned earlier, the outcomes in the laboratory are now recognized as being more than mere content acquisition.

The majority of outcomes measured are largely in the cognitive domain and the principal evaluative paradigm is the empirical-analytic, the conventional one. Growth in the affective domain has been little researched -- the attributes are difficult to measure and very time consuming (Pawloff, 1974). Indeed, "the affective growth of students in the science classroom is virtually ignored. If any growth does take place, it is usually insignificant ... and develops by chance or as a by-product" (Nay and Crocker, 1970 p 2).

The reseach on the evaluation of achievement in the sciences has been the main concern, until recently, while the evaluation of laboratory activities, particularly the process skills in the laboratory, was ignored. The classroom teacher in Alberta has had few evaluative instruments provided for him. Prior to 1973 the Alberta Department of Education issued compulsory final examinations for students seeking senior matriculation from an Alberta high school, but these tests contained few questions about the student's work in the laboratory. The questions which did appear dealt mainly with scientific knowledge, and the process skills and the affective attributes were absent. Tamir and Glassman (1970), on this issue, insist that students will be motivated to a much greater degree if they "know they will be examined on laboratory competences and procedures..." Kruglak (1954, 1955, 1959) showed that laboratory skills are difficult to properly evaluate by means of paper-and-pencil tests and probably can only be done in a valid manner with "performance tests". Jeske's survey on methods of evaluating practical activity (1980, p 60) includes the Klopfer Model--a scheme for categorizing the range of student behaviors. Klopfer's objectives of developing skills in using laboratory equipment and performance of common laboratory techniques are effectively assessed by the practical examination, but the best way to assess the student's skills in the Processes of Scientific Inquiry, is to observe the student while engaged in inquiry. The action component of the affective domain (attitudes and interests) in the Klopfer model are also assessed by observing students in action (Klopfer, 1971).

The multitude of competencies required by students performing laboratory work has been analyzed by several educators: Taxonomy of objectives in the cognititive domain (Bloom, 1956); taxonomy of objectives in the affective domain (Krathwohl et al, 1964); inventories and categories of process skills (Nay et al, 1971 and Klopfer, 1971). These taxonomies and inventories determine levels of scientific inquiry described by Schwab, and they attempt to describe common rather than specific acts and processes needed in the science laboratory.

In the present study, Nay's inventory, An Inventory of Processes in Scientific Inquiry (See Appendix C), was chosen over the other schemes as a model for evaluating behavioral objectives in the laboratory. The inventory is, of course, more than an evaluation scheme. It is a model for instruction--a model with structure that parallels the format (form and sequence) of the experiments used in ALCHEM and yet is not too rigid. In addition, the inventory contains a more extensive list of processes in scientific inquiry than the other models mentioned. The inventory has been used with the students of this study as a guide to understanding the research behavior of scientists and as an annotated list of process skills which students are likely to exhibit before, during, and after a laboratory experiment.

Empirical-Analytic Paradigm

The parameters of the empirical-analytic type of research (also called technical, normative and sometimes scientific) are reliability and validity (Kerlinger, 1964). The evaluation is perceived as means-ends. It is achievement oriented and goal based. The notion that life and reality are "out there" and can be explained with certainty and predictability is a paramount belief of achievement oriented evaluators. The way of knowing is empirical and our understanding of knowledge comes from facts, hypotheses, theories, and laws (Aoki, 1978). Evaluators in this paradigm set up predetermined goals then determine the realization of these goals by stressing measurements of student achievements. Critics of this paradigm suggest that the student becomes indoctrinated through a process of training and "inculturation" before he is allowed to determine his own valid point of view (Rothe, 1979, pp. 21-27).

The Tyler rationale which has been perhaps the most persistent model in curriculum evaluation has been, in Kliebard's words, "raised almost to the status of revered doctrine." Kliebard points out that if educational objectives need only be consistent with one's educational philosophy, then we had better take a good look at the educational philosophy. Although the objectives are drawn from studies of the learner, studies of society, and suggestions from subject matter specialists, this still leaves us with the problem of arriving at a proper philosophy (Kliebard, 1975, pp 70, 77, 80).

The Stake model consisting of Intents, Observations, Standards, and Judgments has a difficulty. Called the "if-then program", the model rests on the rationale (Standards) of the experts, and it is the rationale of the experts which need to be critically examined (Taylor and Cowley,1972, p 96).

Research testing systems such as pre and post-tests, questionnaires, analyses, etc., have a technical interest in knowledge. The technical knowledge is valued for itself as being "precise, transmissible, and innovative, its acquisition is inspired by desire to dominate the worlds of nature, humanity, and society..." (Gurvitch, 1971, p 29). Habermas (1971, p 309) calls this the "cognitive interest in technical control" and names it the empirical-analytic approach to evaluation in research. The process-product reasoning in industry with its stress on systems management and accountability has permeated with force into the school; and this reasoning often reduces people to "manipulative abstractions" (Apple, 1974, p 10).

Speaking on predetermined behavioral objectives, Apple quoting Bernstein says,

> One can value, say, predetermined behavioral objectives for their supposed ability to lead to measurable outcomes (their efficiency as means to reach previously chosen ends); however, the very notion that such reductive and atomistic curricular formulations are worthwhile educationally in themselves is an arguable assertion to say the least. It can certainly be argued that they embody an ideology of control, that they place much too high a value of certainty above all else, that they are inaccurate representations of and trivialize the processes of inquiry... . (Apple, 1974, p 11)

To conclude the review of the literature on the prevailing paradigm, a word from Power seems in order. Power (1976, p 579) reiterates that the traditional paradigm employs acceptable standards of procedures and demands rigorous objective treatment of data collecting and processing. The rules are well established and they have worked for most types of research; however, in science education they impose constraints.

> The results may be valuable to research workers in the same field, but rarely has the experimental path yielded anything of real significance to science teachers or had any real impact on practice. (Power, 1976, p 592).

The review of the literature has uncovered some rather harsh words about the worth of predetermined behavioral objectives and about the empirical-analytic orientation which has been responsible for much useful research. For the present study, the undeniable inference from these views is that other perspectives are needed if the ideology of control is to be broken, and if the positive-rational action that Habermas says tends to depersonalize human interaction is to be arrested. Perhaps we in education are indeed trained, as Apple says, "to believe in the efficacy of our technical expertise" (Apple, 1974, p 16).

The review of the literature has also revealed that the predominant paradigm when applied to research in science education, at least, has produced an inordinate number of conflicting results. It has also produced a large number of studies with "no significant difference" in the results. Furthermore, studies in this paradigm are too restrictive. Only a narrow view of reality is being investigated largely due to two prerequisites: objectivity and controls. Oldham (1981) in an analysis of current paradigms in science education research cites several contemporary researchers who found the dominant paradigm wanting: Bowen (1975), Driver and Easley (1978), Jenkins (1976), Kempa (1976), Lovell and Lawson (1970), Patton (1975), Roberts and Russell (1975), and Sanders and Schwab (1979).

The classroom and the laboratory are seen as complex settings which, if to be effectively evaluated, require additional evaluation paradigms. The criticisms of the empirical-analytic paradigm discussed so far justify to some degree the direction of this study. Employing a dual approach, (the empirical-analytic and the situational-interpretative--previously defined in Chapter I) this study emphasizes the situational-interpretative paradigm to a greater extent, not only on the basis of the criticisms by Rothe (1979), Kliebard (1975), Power (1976), Apple (1974), and Oldham (1981) but also because of the size and nature of the population of the main study. Rigorous and significant empirical conclusions can hardly be expected from a study which employs an unrandomized population of only twenty students. To investigate the problem of this study solely by means of the empirical paradigm would necessitate adequate randomization, stricter controls, and a much larger population--all either impossible or unmanageable. Even if some of the extraneous variables (intelligence, motivation, dedication, enthusiasm of the teacher, etc.) could be controlled, thereby increasing precision of results, generalizability would unfortunately decrease.

Situational-Interpretative Paradigm

The anthropological paradigm employs the ethnographic approach (Power, 1976) and is called the situational-interpretative by Habermas. This approach

> demands that the investigator does intensive fieldwork in classrooms of a kind which allows him to become a participant observer rather than a detached scientist manipulating, controlling and measuring people and events. (Power, 1976, p. 582)

Aoki insists that this type of research in curriculum evaluation is vitally complementary to the traditional type of research. The researcher must communicate: "clarify motives, authenticate experiences and common meaning." (1980, p 12)

Using Habermas' three orientations (empirical-analytic, interpretative, and critical-theoretic) Aoki argues that the three orientations can be used not only for research but as paradigms for curriculum development and evaluation. By interpreting people's perceptions about a program, the researcher determines whether a program is relevant, meaningful, and worthwhile (Aoki, 1978, p 14).

Power's "philosophical" paradigm resembles Habermas' critical-theoretic. To answer the question "What is educational about educational research?", Power argues that the question may have a solution if subjected to a systematic philosophical analysis (1976, p. 584). The researcher, using the critical inquiry perspective, says Aoki, must "himself become part of the object of the inquiry." (1980, p. 13)

A scheme to classify evaluation models is suggested by House (1978, p 12) who makes use of classification models by Stake (1972), Popham (1969), and Worthen and Sanders (1973). The taxonomy which House describes includes eight models in a grid of "critical dimensions" listed vertically for comparison. These include designations such as proponents, methodology and outcomes. As one moves down the methodology column the research methods become less academic and more phenomenological. As one moves down the outcomes the overall concern emphasizes more personal understanding. House, for example, labels Tyler's model of behavioral objectives as utilitarian -- one which employs traditional academic models; whereas, the proponents of Stake, Smith, MacDonald and Parlete-Hamilton have models termed transaction and are ones which use case studies, interviews and observations as their methodology.

The Pilot Study uncovered useful techniques and general methodologies of the situational-interpretive paradigm; and these research methods have been applied to the evaluation of the laboratory teaching strategy of this study. Several ethnographic investigative techniques found in the literature are examined in the following section.

Participant Observer

Wilson et al (Center for New Schools, 1974) found that goals reached from data collected from interviews, questionnaires, and observations were best attained when participants were involved, whenever possible, in the design and activity of the data collected. The evaluators found that informative feedback helped to shape on-going programs and helped participants reach their goals. "Evaluators have a responsibility to help people...be successful in their endeavors... . The people should feel like co-evaluators." (1974, p 5). The researchers discovered that participant observation, although time consuming, was a very powerful technique for gathering reliable and valid information about changes in student behavior (1974, p 24).

There is no one right method in ethnography suggests Wilson (1977) who advocates that researchers, during the review process, concern themselves with the following issues and questions:

> What was the researcher's role, training and previous experience?
> What were his personal feelings about the study?
> Who supported the study?
> To what extent did he become a participant?

Other questions which help to understand the perspectives of the participants and pertinent to the present study are:

> How long was the researcher in the setting?
> How regularly was he there?
> Where did he spend most of his time?
> With whom did he spend most of his time?
> How well did he understand the language of participants?
> How was he perceived by various groups of participants?
> Was there systematic variance in his understanding of the perspectives of various groups?
> What were the levels of confidence the researcher placed in various conclusions?
> What was some of the negative evidence?
> (Wilson, 1977, pp. 261-263)

Sindell (1969), reporting on various studies, found that the teacher working alone is severely handicapped when doing this type of research work because he is emotionally involved in that which he is trying to study. In additon, the teacher is faced with a "tremendous amount of social interaction he must initiate and react to while teaching" (1969, p. 605). Since one cannot observe everything one must be selective, and the activities which occur frequently and with a high degree of frequency are those to be preferred says Spradley (1980, p. 62). He cautions, however, that the less familiar one is with the social situation, the easier it is to "see tacit cultural rules at work." Admittedly this was a problem in the present study, and particularly with the Teacher's Log. Someone unfamiliar with the students and the laboratory setting might be more perceptive in some situations; however, knowing each student personally created more advantages than disadvantages. Students do not always say exactly what they mean, and in order to "read between the lines" one must know the student well.

Some salient techniques suggested by Bruyn (1966) are: The participant observer shares life activities on a face-to-face relationship; the observer requires both detachment and personal relationship; and yet, his social role is to be a natural part of the cultural life. The balance of objective detachment along with personal involvement was found particularly difficult during the pilot stage, although some data gathering techniques were refined by involving students. Students were asked to criticize the statements and the frequency of the questions on the quesitonnaires, for example. They were asked (anonymously) if the presence of the teacher affected their responses to questionnaires, taped interviews, and written comments.

Techniques developed by Spradley (1980) have been used in a recent study by Cuyler (1981) who set out to interpret the philosophies of art galleries. In Cuyler's (1981) analysis, order and category emerged from her data which permitted her to discover meanings in the behaviors of docents. One of Spradley's three ethnographic analyses, the taxonomic analysis, was adopted for this study. The purpose of this taxonomy is to show how domains are organized and related. For example, the investigator can focus on a stage and determine by observation or interview such questions as:

> How many students can initiate the activity on their own? Which students cannot? Why not?
> How many initiate action by observing others? Why?
> How many change their initial actions? Why?

Summary

In order to investigate a broader view of the laboratory scene, the situational-interpretative has been chosen as the predominant paradigm. The principle techniques for gathering data to assess the problem of this study utilize three tests in the empirical-analytic (a chemistry achievement test, a process skill test, and a scientific attitude test); whereas, in the situational-interpretative paradigm questionnaires, written statements, taped interviews, and field notes ("participant observer's" notes) are used.

The particular theoretical framework from which this study has been carried out is one which includes all three domains (concept, process, and affective) and employs a di-paradigmatic approach to evaluation--empirical-analytic and situational-interpretative.

CHAPTER 3

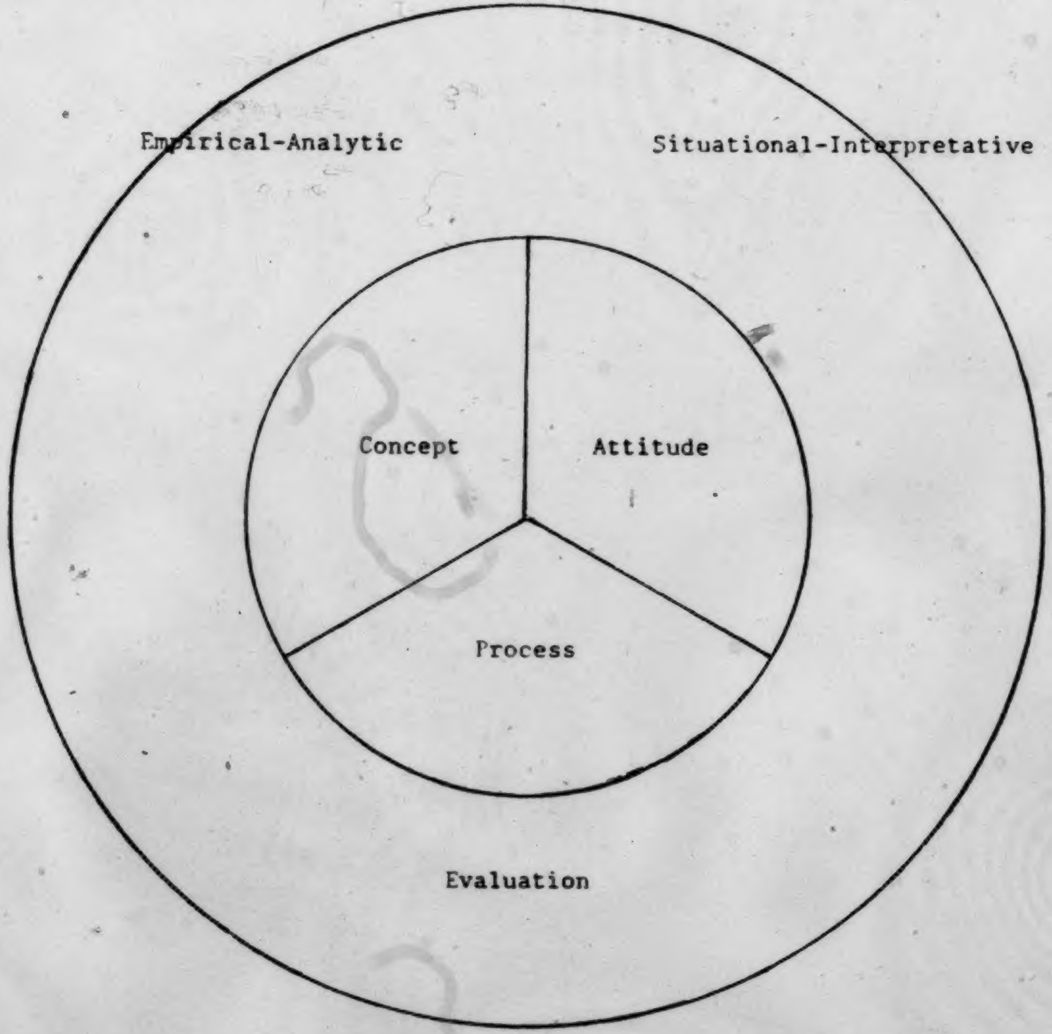
EXPERIMENTAL DESIGN

This study is a qualitative-quantitative investigation of inquiry learning and teaching in a high school science laboratory. As mentioned earlier, the study is an attempt to determine the extent to which students can exhibit objectives in the concept (higher level), attitude, and scientific process skill domains if they are presented with minimally structured laboratory investigations. In addition, the subjective meanings and feelings that students attach to their behavior regarding this type of inquiry learning are investigated. A di-paradigmatic approach, a blend of empirical-analytic and situational-interpretative paradigms, is the research mode and is depicted in Figure 1.

This chapter provides the rationale for the design of the study, and centers around the teaching strategies employed in the Revised ALCHEM 30 experiments. An outline of the testing instruments, the investigative techniques, the pilot studies, and the main study is followed by the manner in which the collected data were analyzed.

Figure 1

Experimental Design: Dual Evaluation in the Three Designs


Empirical-Analytic
Situational-Interpretative
Concept
Attitude
Process
Evaluation

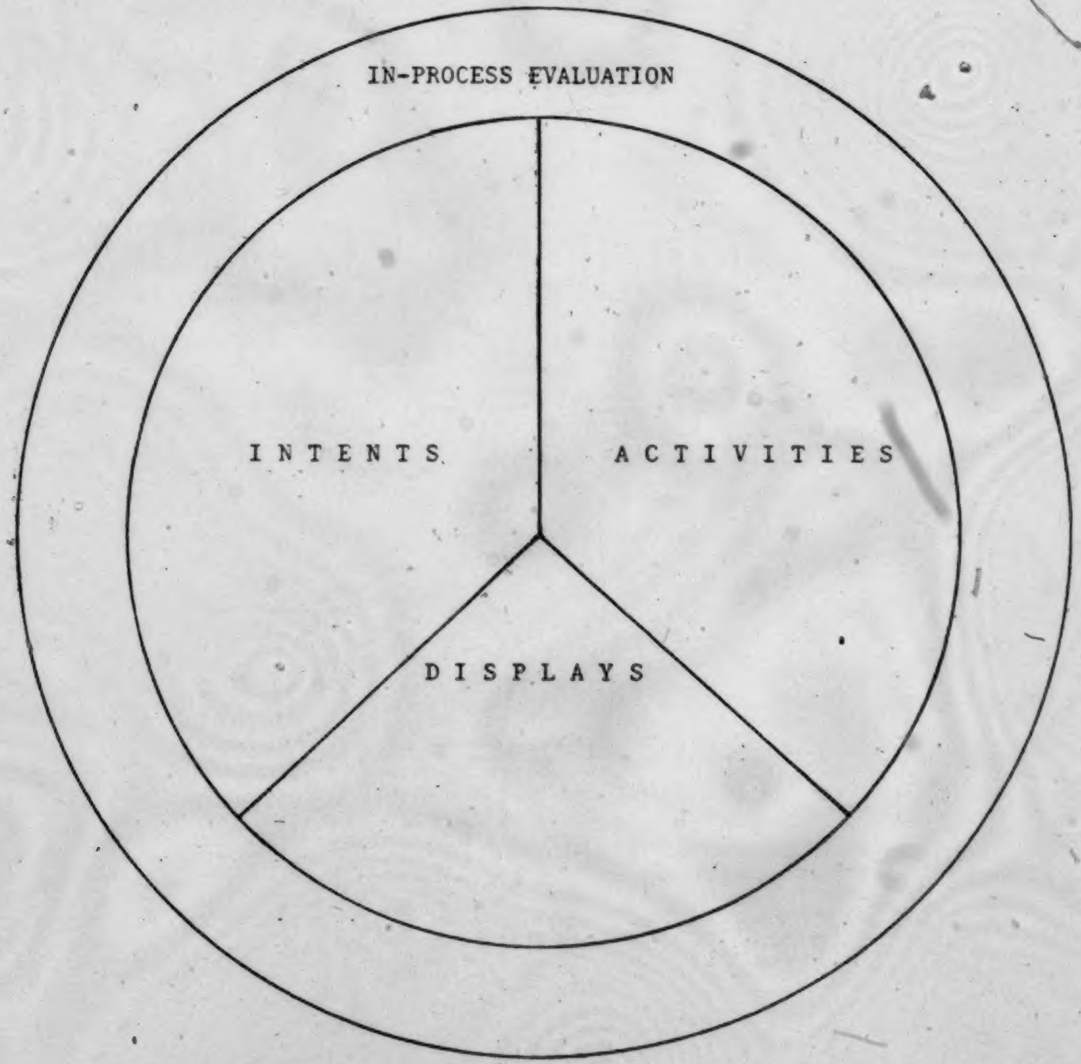
Model Used for the Study

This study is based essentially on the Werner and Aoki (1979) model given in Figure 2. Its components of intents, displays, activities and evaluation (IDA/E) illustrate the "why" (the intents), the "how" (the activities) and the "with-what" (the displays) of this study. The intents encompassed the notion of teaching and learning chemistry mainly through high level inquiry in the laboratory setting, the outcomes of this type of pedagogy, and the student's and teacher's (investigator's) subjective thoughts and feelings about this approach. The activities consisted mainly of student engagement in chemistry investigations in which they had to contribute to the solution of the posed problems and submission of their reactions to these activites. These activities are based on scientific process skills (Appendix C). The displays consisted of printed instructions for the investigative activities (most of which were ALCHEM ones revised to incorporate a higher level of inquiry), the materials required for the laboratory activities, and the instruments for collecting data for the study.

The circular model in Figure 2 also serves to emphasize the fact that this study utilizes formative and summative evaluations. Evaluation, in this study, must play a major role, and the approach is the "in-process" type of evaluation referred to by Werner and Aoki (1979, p 60).

Figure 2

IDA/E Evaluation Model


IN-PROCESS EVALUATION
INTENTS
ACTIVITIES
DISPLAYS

This evaluation, also called "formative evaluation", is essential to students since it makes them aware of their progress on a continuous basis; it is also essential for the curriculum development of this study since feedback provided by the in-process evaluation gives direction on a continuous basis for the program. The pilot phase, the initial in-process evaluation conducted for two semesters (1981, 1981-1982), produced several changes in design and implementation of the study. These will be discussed later in the chapter.

Evaluation is always implicit in defining intents and selecting displays and activities, but the in-process approach emphasizes the need to constantly "question the criteria used" in the selection of intents, activities, and resources (Werner and Aoki, 1979, p 61). Examples of the in-process approach used throughout the pilot phase are explained in the chapter.

The Pilot Studies

Pilot studies were carried out in the 1980-81 semester and again in the 1981-82 semester in an Alberta rural high school, population of approximately 600 students. Three classes including a total of 54 students used ALCHEM 30 materials that underwent revisions throughout the pilot phase.

Students at the beginning of each semester were told about the study and that they would be playing an important role in providing data about field-testing new experiments and various measuring instruments.

Specifically, the pilot phase was used to:

1. field-test and revise the modified eight ALCHEM 30 experiments and the new laboratory experiments L2, M2, and N4 (Appendix B).
2. develop the system of lab reporting (formats, scoring system, administration, time, etc.).
3. determine, for each experiment, if students had sufficient time to perform the experiment and write up the Observation Report in an 80 minute period.
4. develop and refine techniques for data collection for this study (pre and post lab activity, questionnaires, recorded interviews, and investigator's field notes).
5. administer and analyze the results for TOSA, POST and the Chemistry 30 Achievement Test provided by the Student Evaluation Branch, Alberta Education.

Salient modifications resulting from both pilots are as follows:

1. The first experiment in the original ALCHEM 30, Molar Heat of a Phase Change, required students to calculate a heat change which involved a phase change and a kinetic energy change. This experiment was sequenced later in

the unit in the revised experiments because the original experiment was found to be too difficult for students as the first unstructured experiment of the semester.

2. Almost every laboratory experiment exercise underwent some changes in direction (Procedure) and processing of data. Many process directions, for example, were found to be unnecessary because they were too structured. Other directions previously removed had to be reinstated because students simply did not think of doing them.
3. Some of the Prelab Exercises and all Observation tables were deleted since they provided structuring which was found to be unnecessary.
4. Many of the instructions given in ALCHEM 30, particularly under Calculations, were found to be unnecessary. Students performed them because they were essential in achieving the purpose of the experiment. They did not have to be specifically told to perform the interpretations.
5. The original ALCHEM experiment Lab N1 was found to be too short for an 80 minute period and was lengthened by requiring the student to actually perform the tests mentioned as exercises in the Prelab. In addition, students were required to perform 24 tests with indicators (3 indicators with 8 reagents). The original ALCHEM experiment called for only 7 tests.

6. The original ALCHEM experiment Lab N2 was found to be too long and was divided into two experiments. Part A (original) with its 13 procedural steps given became Lab N2 (revised) and the procedural steps were reduced to two. The observation table was removed. Part B (original) became Lab N3 and again all procedural steps and observation tables were removed.
7. In the pilot studies, students found it difficult to finish some of the experiments and structure the data before the end of the period. Students in the main study were requested to have a prearranged scheme for recording data. Further organization of data by students (rearranging, comparing, ordering or classification) was done at a later time and not attempted during the laboratory period.
8. Interviewing more then a few students after each experiment proved unmanageable. For the main study, only two students chosen at random were interviewed for each experiment.

The pilot studies revealed that the revised experiments requiring determinations (e.g., molar heats, titrations and EMF's: Labs L1, L2, L3, M2, M3, N2, and N3) produced higher mean percent errors than for classes using the original ALCHEM 30 materials. Indeed, as the amount of structuring was diminished the class percent error increased. Untried student designs undoubtedly require greater modification and refinement. Invariably, students expected better results than the ones they obtained and many were disappointed with the high percent errors. However, in Lab L3, a typical example, the average error for all pilot classes was only 15%. As a result of these findings it was decided not to penalize students on the laboratory report (FR) for high percent errors. Rather the grade on the report would reflect how well a student performed and realized the objective of the experiment based on his design. Although the percent error was not ignored it was decided that reports with errors generally less than 20% (less for the titration experiments) would not be penalized for the deviation.

The TOSA, POST and Chemistry 30 Achievement tests were administered to the last class in the pilot phase so as to gain some experience in their use and to obtain some preliminary indication of the effect of an inquiry teaching strategy in the laboratory. TOSA was used to assess the effect of this strategy on the scientific attitudes of Grade 12 students. Similarily, the Processes of Science Test (POST) was administered to measure change in the process skill domain. Regarding TOSA, a pre- to post-test design with no control was employed, and the effect of the semester treatment of laboratory inquiry teaching produced a significant change in pupil attitude as measured by TOSA. See Table 1. The same comparison was not possible with POST. The pre-test was administered at the beginning of the year but school was closed because of inclement weather on the day the post-test was scheduled. Since this day was the last day of regular classes for Semester I, the test could not be rescheduled.

The purpose of the Chemistry 30 Achievement Test, administered as a post-test, was to see if students subjected to the strategies of the pilot (which called for much more time in the laboratory than in the classroom) would be penalized on a conventional content examination such as the Alberta Education Achievemnt Test in Chemistry 30. Students from the pilot compared favorably with the provincial group scoring 17% higher than the mean established by Alberta Education, a mean based on 136 students.

The Main Study

The main study was conducted in the second semester of the 1981-82 school year. It involved an experimental group of students consisting of 12 girls and 8 boys. The design employed was similar to that described for the pilot phase, except that the revised procedures, materials and instruments were used. These are now discussed below.

TABLE 1

Pilot Study Results for Test Instruments

Test	n	Pretest Mean	S.D.	Post-test Mean	S.D.	Difference	t Value
TOSA	30	24.40	3.59	25.87	3.72	1.47	2.21*
POST**	30	28.86	5.35				
Chem 30	18			45.83	8.31		

* Significant beyond the p=0.05 level.

** The post-test for POST was not administered.

The Teaching Strategy

A typical two week period in Chemistry 30 consisted of approximately 560 minutes of regular classroom activities (lectures, demonstrations, homework corrections, and evaluation) and 240 minutes in the laboratory and with laboratory related activities such as pre- and post-lab sessions.

The essential aspects of the teaching strategy used in the study component are as follows:

1. Introduction of Scientific Process Skills
2. Prelab Activity
3. The Laboratory Activity
4. Postlab Activity

Introduction of Scientific Process Skills

At the beginning of the term prior to the experimental work students were introduced to the objectives of the laboratory work. Specific objectives are listed at the beginning of each unit in ALCHEM 30 but these objectives, which include some behavioral objectives, are generally concerned with the content of science (knowledge, facts, principles, theories, etc.) The processes of scientific inquiry--the general processes that scientists use in discovering knowledge--had to be delineated and discussed, using the "Inventory of Processes in Scientific Inquiry" by Nay et al (Appendix C). However, the most important avenue for the students acquiring knowledge of and skill in these process skills was through performance of the experiments.

Prelab Activity

Usually the day before each experiment at least part of the lecture period was devoted to class discussions and demonstrations about the forthcoming experiment. The briefing was not used to give additional information or instructions to those given in the laboratory exercises but rather to clarify instructions for pupils who were having difficulties with those given in the printed materials (Appendix B).

Since most students, at the beginning of a unit, have limited laboratory skills and lack general knowledge about the concepts and related facts, the prelab activities tended to be in more detail for the first experiment of each unit. For example, at the beginning of the year students were made aware of the use and the limitations of all necessary measuring instruments (graduate cylinder is ±1 mL, thermometer is ±0.1°C, centigram balance is ±0.01 g, etc.) In addition to the above, the majority of the laboratory experiments included some prelab exercises which further developed the problem to be investigated. With few exceptions, the prelab exercises were identical to those of the original ALCHEM experiments.

Cooperative planning of the upcoming experiment involved the following activities:

1. Students were helped to identify and formulate the problem.
2. Salient process skills were discussed.
3. Safety precautions were discussed.
4. The use and care of special equipment was demonstrated.
5. Students were guided to necessary theory and sources of information.

The Laboratory Activity

With the exception of Lab L2, students performed all the experiments at the work bench individually. Because of the multitude of operations required and to some extent the risk of injury (e.g. burns from escaping steam), students performed Lab L2 in pairs.

Students performed the experiments during the time scheduled for Chemistry 30. However, provisions were made for extra laboratory time when needed--before school, during noon hours, during free periods, and after school. The extra time was necessary for those students who required more data or whose initial design proved unsatisfactory.

During the work period of the experiment the teacher was involved in the following activities:

1. Pupils were observed to see if they were following their own designs.

2. Students were helped with minor lab techniques and skills but were not given a better way to perform the skill. (The unwritten rule during the lab session was "solve your own problems.")
3. Equipment, materials, reagents, etc., were provided for students who had changes in design.
4. Hazards were minimized.
5. Students were allowed to make mistakes but, whenever possible, an attempt was made to find out if students realized their mistakes.
6. Although students were generally left alone during the work to perform the lab and solve their own problems, occasionally pupils were questioned to determine if they were making reasonable inferences from their data.

Student progress in the laboratory activity was promoted and monitored by means of three laboratory reports, to be submitted by each student for each experiment. These reports were a Design Report (DR), an Observation Report (OR), and a Final Report (FR). The treatment for each report was as follows:

Design Report (DR). Each student, before going to the laboratory bench, had to submit a report which included the design he intended to follow. This insured that students were adequately prepared for the laboratory experiments, gave them an opportunity to develop skill in designing experiments, and provided evaluative data for this study on student acquisition of process skills.

The Design Report was submitted on a form provided. It showed the experimental steps including the expected sequencing. Students were told to be specific and to be particularly quantitative in their experimental steps. The student was not bound by the original design; indeed, the original design may have resulted in failure and would require modification. The student may have to resort to a trial and error approach to design. If changes were made, they had to be reported on the Observation Report at the end of the laboratory period.

Observation Report (OR). At the conclusion of the laboratory period, students were to submit an Observation Report on a form provided containing all the data collected during the experiment. Each student kept a carbon copy of the report so that the data could be processed at a later time.

Students were encouraged to draw up a scheme for recording data before the actual performance of the experiment. For many students data was initially recorded in an unstructured fashion to be processed and interpreted later in the Final Report.

Final Report (FR). Within two days after the laboratory period, students were required to submit the Final Report in a format of their choice. This report was to include:

1. how the data were processed
2. calculations, percent error, sources of error, etc.
3. interpretations: the extent to which the problem was solved, validity of assumptions, explanations, etc.

The laboratory report serves a dual role. On the one hand it is a teaching strategy, the activity in which the student is engaged while performing an experiment; on the other hand it is an evaluative instrument for the process skills involved in inquiry. In the laboratory students attempted to learn and utilize the scientific process skills necessary for their inquiry (some suggested by the exercises and some provided by themselves). The data of the reports served as the quantitative basis for evaluating the manner and extent to which students attained the requisite objectives. The reports also revealed to what extent students made sense of their data and whether the experimental steps produced legitimate data, data which were sufficiently complete to enable the problem to be solved.

Postlab Activity

After the laboratory reports were returned to the student approximately 30 minutes was spent in the classroom discussing the experiment, its theory and the process skills applicable to the experiment. Improvements in design, observations and processing data and errors in the use of equipment were discussed. Class averages and percent errors were also discussed. Continuity with previous experiments and appropriateness and relevance to course material were also covered. Time was spent on higher process skills such as "conceptualization of data" and "open-endedness" because they were difficult for students to exhibit. For example, the generalization of molar heat of a phase change from Lab L2 was used to formulate ways and means of measuring the molar heat of melting for ice in Lab L3. Students were unaware that this was the problem for the next laboratory experiment, Lab L3. This is an illustration of open-endedness: seeking further evidence to (a) increase the level of confidence in the generalization, and (b) test the range of applicability of the generalization (See Appendix C). But before the end of the activity period, the teacher guided the discussions in an attempt to engage students in a "free discussion" (not teacher directed) about their attitudes and feelings regarding this particular mode of learning. The classroom discussions after each experiment had a dual purpose: one was to help the student better understand his performances in the laboratory, the other to provide data for the study. Pertinent findings from these discussions are included in the Teacher's Log, Appendix N.

The Revised ALCHEM 30 Experiments

The revision consisted of modifying the eight experiments in the ALCHEM 30 program and adding three new ones. Each unit in ALCHEM 30 has three laboratory experiments with the exception of the Energy Unit (Unit L) which has two. The revised laboratory experiments (Appendix B) for this study include three experiments in Unit L (Energy), four experiments in Unit M (Electrochemistry), and four experiments in Unit N (Acids and Bases). Consequently, this study has fifty percent more experiments than the original ALCHEM 30 laboratory requirements.

The ALCHEM 30 experiments were revised to incorporate a higher level of inquiry. In the modification, the problem, materials and prelab instructions remained the same as in the original experiments, but the procedure, observing, calculations and questions were more unstructured; that is, students were expected to design and sequence the experimental steps, tabulate observations and process data in their own way. When a revision was complete, all the original experiments were removed from the students' ALCHEM package of materials and the revised experiments substituted.

As can be noted in Tables 33 and 43 in Appendix B, the experiments in each unit are sequenced in such a way that the amount of guidance provided by the labortory manual and the teacher diminishes with each subsequent experiment. The first experiment in each unit is the most highly structured while the last is the least structured. Experiments which have the least amount of guidance presumably demand from the student the highest level of inquiry. Since the skills and the techniques differ from unit to unit, the gradation of levels of inquiry is necessary to provide an early opportunity for the student to learn the necessary general knowledge and to become familiar with the requisite laboratory skills and techniques of the unit under investigation.

In Appendix D and Table 2 the number of process skills required for the ALCHEM 30 experiments are compared with the Revised ALCHEM 30 ones. The relative emphasis of each specific process skill is determined by the nature of the experiment. No single experiment necessarily contains all the process skills listed in the Inventory (Appendix C). However, as can be noted from Table 2, it was possible to increase the number of process skills in several of the experiments (L3, M1, M4, N1, N2).

In Table 2 it can be seen that students have a substantially greater input into the solution of the problems in the revised experiments than in the original ones, hence by definition must operate at a much higher level of inquiry. Indeed they are required to initiate 231 out of the 355 steps, (65% of the total) as compared with 75 out 243 (or 31% of the total) in the original ALCHEM experiments. In terms of Nay's definition of level of inquiry (Appendix D) the laboratory activity in this study must be considered to have been conducted at a very high level.

The Data-Collecting Instruments

The instruments used in this study are divided into two groups: formal and informal instruments. The formal instruments were used to gather primarily quantitative and analytical data, which could be collected by means of paper and pencil tests, laboratory questionnaires and reports. Specifically the formal instruments included:

1. Otis-Lennon Mental Ability Test
2. Chemistry 30 Achievement Test (Alberta Education)
3. Processes of Science Test, POST (BSCS, 1962)
4. Revised Test on Scientific Attitude, TOSA (Andruski, Kozlow and Nay, 1981)
5. Laboratory Questionnaires
6. Laboratory Reports

TABLE 2

Comparison of Scientific Process Skills in ALCHEM and Revised ALCHEM Experiments

	Total Process Skills Required		Process Skills Initiated by Student	
Lab No.	ALCHEM	Revised	ALCHEM	Revised
L1	35	35	7	16
L2*	-	34	-	23
L3	33	36	6	29
M1	26	27	8	15
M2*	-	33	-	23
M3	32	32	8	19
M4	29	33	10	18
N1	28	34	11	19
N2	29	30	11	22
N3	30	30	14	22
N4*	-	31	-	25
Total	242	355	75	231

* Experiments not part of ALCHEM.

The informal instruments included:

1. Tape-recorded interviews
2. Written statements on the Laboratory Questionnaires
3. Investigator's field notes

The model in Figure 3 classifies the instruments as either formal or informal and depicts the domain in which each instrument purportedly supplies data. From the interactions in the model it can be seen that each domain is covered by at least five instruments. The quantitative data of this study obtained from the informal testing instruments are reported and discussed in Chapter 4. A brief description of each instrument and the reasons why it was chosen are presented below.

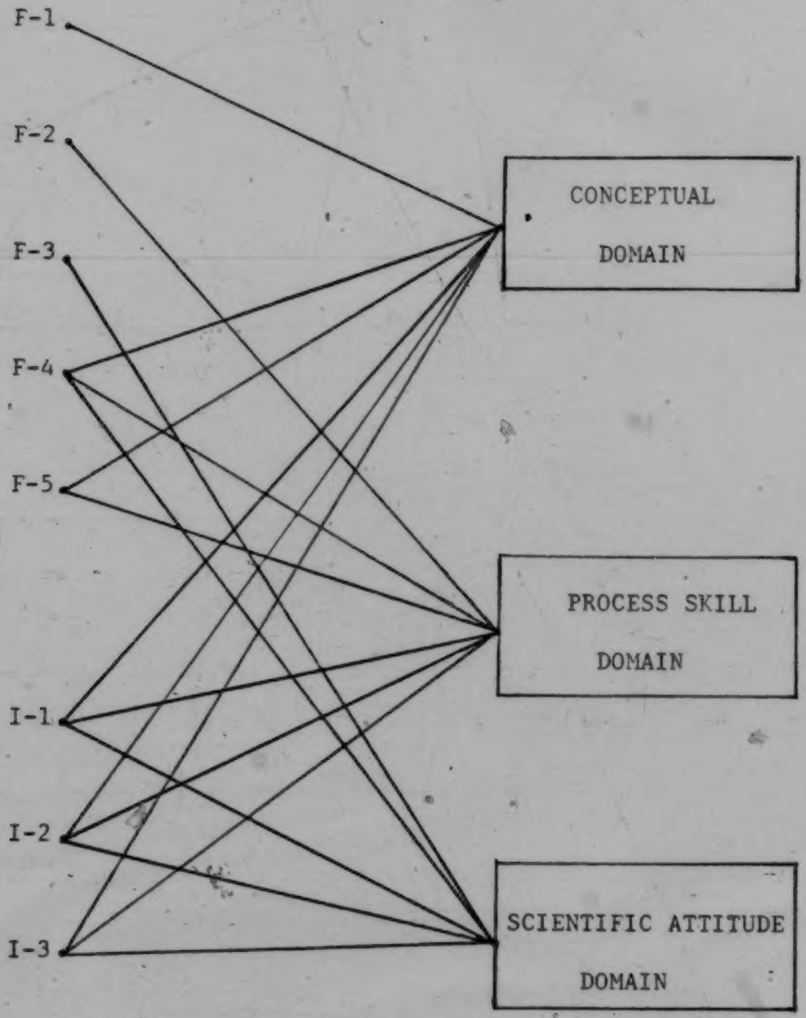
Formal Instruments

IQ Test. The IQ test administered in this study was the Otis-Lennon Mental Ability Test. The score, called a Deviation IQ (DIQ), is a normalized standard score with a mean of 100 and a standard deviation of 16 points. Form J (Advanced level for Grades 10 through 12) was administered to students of the pilot and main study.

Chemistry 30 Achievement Test. This test is a Chemistry 30 achievement test developed by the Student Evaluation Branch, Alberta Education. Permission to use this test was granted by the Director of the Student Evaluation Branch. Permission was also granted to use

Figure 3

Classification of Test Instruments Used in Each Domain


F-1
F-2
F-3
F-4
F-5
I-1
I-2
I-3
CONCEPTUAL DOMAIN
PROCESS SKILL DOMAIN
SCIENTIFIC ATTITUDE DOMAIN

Formal Instruments

F-1 Chemistry 30 Achievement Test (Alberta Education)
F-2 Processes of Science Test, POST (BSCS, 1962)
F-3 Revised Test on Scientific Attitudes, TOSA (Andruski, et al)
F-4 Laboratory Questionnaires
F-5 Laboratory Reports (DR, OR, FR)

Informal Instruments

I-1 Tape-recorded Interviews
I-2 Written Statements by Students
I-3 Investigator's Field Notes

provincial comparative statistical data, such as reliability, validity, means, standard deviation, and item analysis. For reasons of security requested by the Student Evaluation Branch, data on the achievement test and the item analyses are not reproduced in this study, and all copies of the test were returned to the Student Evaluation Branch.

Since the laboratory strategy of this study emphasizes the development of the higher levels of cognitive functioning in the concept, attitude, and scientific process skill domains, it is important to show to what extent students in this study were able to achieve in the higher categories of Bloom's cognitive taxonomy (1956). Although students in the study spent considerably less time learning chemical concepts in the conventional manner, it was hoped that students would not be at a disadvantage in content achievement.

The categories in Bloom's taxonomy (Bloom, 1956) in the cognitive domain which are purportedly being tested by the Chemistry 30 Achievement Test are given in Table 3. These specifications include knowledge, comprehension, application, analysis, and synthesis. The three core units, chemical energetics, acids and bases, and oxidation-reduction, are shown along with the number of questions included in each category of Bloom's taxonomy.

TABLE 3

Test Item Distribution in the Chemistry 30 Achievement Test

ALCHEM	Level's in Bloom's Cognitive Taxonomy						
Core Concepts	Knowledge	Comprehension	Application	Analysis	Synthesis	Total Number of Items	Percent of Total
Chemical Energetics							
1. Each substance has a definite and characteristic heat content or enthalpy.	1	4	0	1	0	6	9.2
2. Changes in matter involve a change in energy.	1	5	6	1	0	13	20.0
Acids and Bases							
3. Acids and bases can be defined in different ways.	3	3	0	0	0	6	9.2
4. The relative acidity of a solution can be measured.	0	2	5	2	0	9	13.8
5. Acid-base reactions involve an exchange of electrons.	2	1	3	0	0	6	9.2
Oxidation-Reduction							
6. Redox reactions involve an exchange of electrons.	1	3	0	2	0	6	9.2
7. In a redox reaction the electron loss and gain must balance.	0	3	3	2	0	8	12.3
8. The electrical potential of a redox reaction can be predicted and measured.	1	0	3	1	1	6	9.2
9. Redox reactions involve electrical energy.	0	1	1	3	0	5	7.7
Total Number of Items	9	22	21	12	1	65	
Percent of Total Examination	13.8	33.8	32.3	18.5	1.5		100

From Table 3 the topical distributions are seen to be nearly equal. This distribution roughly approximates the amount of instruction time suggested in the ALCHEM 30 materials and that which was used in the pilot and experimental groups.

From Table 3, it can be seen that only 13.8% of the questions are at the knowledge level (assuming accurate classification). This level includes the knowledge and recall of facts, rules and principles but not their application. In the hierarchy of levels, application, analysis and synthesis are considered to be the more difficult ones because the mental processing at this level is more complex. There appears to be a deliberate attempt by the Student Evaluation Branch of Alberta Education to evaluate the higher levels of the cognitive domain since over 50% of the questions are purported to be of the application, analysis, and synthesis specifications. Regarding the main purpose of this study, it is assumed that students are therefore being evaluated at the higher levels of the concept domain by the Chemistry 30 Achievement Examination.

Processes of Science Test (POST). POST (Appendix F) is a forty item multiple choice test. It was chosen as a measuring instrument because no other standardized process skill test was found to be as suitable for purposes of this study. It was administered as a pre- and post-test to serve as an indicator of student growth in the process of science. This use is supported by the predictive validity claimed for the test (BSCS, 1965).

POST was designed by the Biological Science Curriculum Study (BSCS) to test a student's knowledge and understanding of the methods of science. Although it is based on biology rather than chemistry content, students in the study were not at a disadvantage because the biological background required for answering a question is given. The process skills that POST measured are indicated in the "Key for Processes of Science Test" in Appendix F. It will be noted that some of the items (20, 21, 22, 32, 34, 35, 39, 40) are not on the process aspect of scientific inquiry. However, they were not omitted when POST was administered to the students in the study.

Statistical data on student performance on POST are based on the administration of the test to about nineteen thousand tenth grade students in the U.S.A. It was estimated that they were slightly above average. A split-half reliability of 0.82 and a test-retest reliability of 0.72 is reported (BSCS, 1965).

Revised Test on Scientific Attitude (TOSA). Tosa was chosen as the measuring instrument because no other standardized test was found to be as suitable for purposes of this study. It was administerd as a pre- and post-test to measure change in the attitude domain. The revised TOSA by Andruski, Kozlow and Nay (1981) was developed originally by Kozlow and Nay (1976) and is based on the Nay and Crocker "Inventory of the Affective Attributes of Scientists" (1970) given in Appendix E. The attitudes measured by TOSA are objectivity, open-mindedness, honesty, suspended judgment (restraint), respect for evidence (reliance on fact), willingness to change opinions, critical mindedness, and questioning attitude (Kozlow, 1973, pp 38-39). TOSA is divided into two subtests: the cognition one measured the student's understanding of how scientists behave attitudinally while doing research, whereas the intent subtest measured the intended attitudinal behavior or "behavioral intent" relative to the defined science situations.

The Kozlow and Nay study (1976) indicated that the cognitive and intent subtests did not measure the same characteristics. An understanding of how scientists behave was not sufficient to "ensure that students will demonstrate these characteristics in their own science work or in their own every day situations. Teachers must consider this difference when planning classroom activities and evaluating student development" (1973, pp 119-120).

Content validity of the substantive component is claimed for TOSA on the basis that

> the attitudes which the test is designed to measure were selected from a list of affective attributes of scientists; the behavioral specifications of these attitudes were selected on the basis of the responses of a panel of judges; the content of the items describe science-related situations; and the content of the items is comparable with the ideas expressed in a wide variety of science reading material. The validity of the keyed responses has been demonstrated by a panel of judges. (Kozlow and Nay, 1976)

Structural validity for the test was established on the basis of factor analysis. The empirical structure underlying the test item, as identified by a factor analysis solution, correlated highly (75%) with one predicted from a behavioral definition of the attitudes (Kozlow and Nay, 1976).

The revised TOSA (Appendix G) was administered in 1980 to about 1200 students consisting of roughly equal numbers of grade 10, 11 and 12 students taking biology, chemistry reliability coefficient of 0.64 is reported for the whole test. The KR-20 correlation coefficients for the cognition and intent subtests are given as 0.53 and 0.43 respectively. The correlation between the two subtests is 0.41.

The key for TOSA is given in Appendix G. A panel of seven judges provided the answers to the test items and to the classification of these items into the attitudes being tested and into the sub-tests.

Laboratory Questionnaires. A separate questionnaire (Appendix M) was administered after each laboratory investigation including content, attitude and process skill questions. The questionnaires were designed by the investigator and refined on the basis of use in the pilot phase and reaction from Dr. Nay. The questionnaires provided descriptions of what happens in inquiry-oriented laboratory activity in terms of students' concerns, difficulties, priorities, interactions, likes, dislikes, and personal feelings about participation in the laboratory program.

Since this study is an attempt to discover the feelings students have for operating at the higher levels of inquiry, it is important to determine attitudes and personal feelings that students have for designing and sequencing their own experimental steps, tabulating and ordering their own observations, and processing and interpreting their own data. Although the questionnaire was used primarily to gather data in the affective and process domains it was also used in the concept domain to determine how well students understood the principles exemplified in each experiment.

Laboratory Reports. As was stated earlier students were required to complete three reports for each laboratory experiment: Design Report (DR), Observation Report (OR), and Final Report (FR). The first two were written on forms provided. These reports were designed by the investigator for the intitial pilot study in 1979-80 and refined during the 1980-81 pilot phase. They seemed well suited for the purposes outlined above in the section on "The Teaching Strategy".

The authenticity of some of the student reports may appear questionable. For example, there was no guarantee that the student's design report was indeed his own and not copied from someone else. However, the originality of the report was seen as a good indicator of authencity. Furthermore, student cooperation was sought at the beginning of the semester during the pilot phases and the main study with the result that few problems regarding the authenticity of the design reports arose. Because of the circumstances under which the observation report had to be completed the validity of this report was not an issue. Although the student sought help from classmates, ALCHEM materials and library in processing data for the Final Report, he had to use his own data.

The criteria used for evaluating the reports varied from report to report but generally one mark was deducted from a report for the omission of any of the skills listed in the Criteria for Evaluation of Reports (Appendix J). Each student received a copy of these criteria at the beginning of the semester. The Design Report and

Observation Report were marked on a scale of 0 to 5 while the Final Report was marked on a scale of 0 to 10. Usually the percent error or the student's deviation from the accepted value is considered the important criterion for evaluating a final laboratory report, but in this study the extent to which students achieved the purpose of the experiment based on their design was regarded, to be of greater importance.

The Informal Instruments

The informal instruments (tape recorded interviews, written statements on the questionnaire and investigator's field notes) provided data for the situational-interpretative dimension of the analysis of inquiry oriented laboratory teaching. They were designed to uncover personal reactions to the program such as whether the laboratory program was perceived by students to be worthwhile, whether the program was appropriate to their concerns, and whether they felt confident in learning chemistry by the approach used.

Taped-Recorded Interviews. Only a small sample of students were interviewed because it is generally recognized that interviews in phenomenological research are time consuming. After each laboratory experiment two students, randomly selected, were interviewed using a tape-recorder. All of the students were interviewed once but in rotation on the basis of two students per experiments. The sessions, lasting approximately thirty minutes, took place during the noon hour, spare periods, before and after school hours. The first part of the interview consisted of questions on how students felt about the strategy of the laboratory and what they liked and did not like about it. The second part consisted of specific questions related to the topic investigated (Purpose), the pre-lab discussion, design, observation and processing of data, laboratory reports (DR, OR, FR) and marking of reports. The last part of the interview was related to how the students felt about their peers and the teacher. At the end of the interview students were asked to express their feelings on any facet of the laboratory program. The interview questions along with the edited student responses are found in Appendix L.

Written Statements. Additional qualitative data were collected during the semester of the main study by means of written statements from students. The questionnaires administered at the end of each laboratory experiment provided space for written comments, and students were asked to express their personal feelings and attitudes regarding their participation in, or any facet of, the laboratory program. Edited summaries of the written comments are found in Appendix N.

Investigator's Field Notes. During the main study the teacher (investigator) kept notes on student activities and attitudes. The circumstances under which the statements were made was also recorded. These notes, periodically reviewed and condensed, were transferred to a Teacher's Log (Appendix N). After each laboratory session, notes were made on student activities during the prelab discussions, the laboratory work period and the post-lab discussions. The log is an attempt to understand the perspectives of the students while they are participating in the unique activities of the laboratory program.

Summary of Chapter

In this chapter a theoretical framework for the design of the study was described. In order to investigate inquiry learning and teaching in the chemistry laboratory, students and student activities were evaluated in three domains (concept, attitude and process skill) by several data-gathering instruments. Five formal instruments (Chemistry 30 Achievement Test, Processes of Science Test, Revised Test on Scientific Attitudes, Laboratory Questionnaire, and Laboratory Reports) provided data for both the empirical-analytic and situational-interpretative dimensions. The first three instruments provided summative evaluations while the last two provided formative evaluations or evaluations in-progress. The fifth instrument, the Laboratory Reports, in addition to providing data for this study provided continual feedback to the student about his progress in the use of the process skills.

The three informal instruments (Tape-recorded Interviews, Written Statements, and Investigator's Field Notes or Teacher's Log) provided data for the situational-interpretative dimension. The first two instruments were used by asking students specific questions in the three domains while the Investigator's Field Notes were periodic records kept on student activites and attitudes. These three instruments provided the necessary data to determine the relevance and meaning which the inquiry-oriented laboratory program had for the students involved.

CHAPTER 4

QUANTITATIVE RESULTS AND DISCUSSION

The quantitative data which are part of the empirical-analytic paradigm of the present study are presented and discussed in this chapter. In the concept domain, the Chemistry 30 Achievement Test is the instrument used. The means from the pilot, experimental, and provincial groups are compared for the reasons mentioned in the last chapter. In the affective domain the Test of Scientific Attitudes (TOSA) is the instrument used, and statistical comparisons of pretest and post-test results are made to determine changes in the students' attitude behavior (objectivity, openmindedness, questioning attitude, etc.) as a result of engaging in high level inquiry laboratory work. The Processes of Science Test (POST) and the Laboratory Reports are the evaluative instruments in the process skill domain. Pretest and post-test results of POST are compared in order to measure changes in student behavior regarding the processes of science (ability to evaluate structure of experimental design, appraise data, recognize need for controls, etc.). The quantitative results including those for the laboratory reports are compared by measuring the degree of correlation between pairs of variables. The correlations are measured to determine the strength and direction of association between different pairs of variables.

Table 4 shows the means and standard deviations for the data from all instruments. These values are required for the construction of most of the tables in this chapter. In this chapter the results from the quantitative data instruments are discussed under each domain followed by a discussion of correlations between instrument results. Raw data from the quantitative instruments are found in Appendix O.

Concept Domain

The concept domain was evaluated primarily by means of the Chemistry 30 Achievement Examination obtained from Alberta Education. The performance of students from the pilot study, main study and provincial group is indicated in Table 5. The population of the provincial group, consisting of 136 students, is made up of students who wrote the provincial Appeal Examinations. The Student Evaluation Branch claims that students who write the appeals form a representative sample of the entire province. However, due to the availability of scholarships and grants for honor students, many students write appeal examinations because they are trying to raise their marks into the honor category (over 80%).

TABLE 4

Means, Ranges and Standard Deviations of the Quantitative Results

n = 20

Instruments	Maximum Possible Score	Mean	Range	S.D.
IQ	--	115.20	101-130	8.4
Chem 30 Test	65	43.60	33-55	6.1
Pre TOSA	40	24.05	19-33	3.4
Post TOSA	40	25.10	20-38	2.9
Pre Process (POST)	40	31.40	20-38	4.4
Post Process (POST)	40	32.85	26-39	3.2
Laboratory Reports	100	76.45	52-93	10.23

TABLE 5

Mean Scores on the Chemistry 30 Examination for Pilot, Experimental and Provincial Groups

	Pilot Study Group	Experimental Group	Provincial Group
Number of Students	18	20	136
IQ	116	115	*
Chemistry 30 Examination	45.8	43.6	39.1

* Not available

Because all three groups are non-random and small,and because IQ scores were unavailable for the provincial group, a rigorous statistical analysis of scores cannot be made. However, students from the pilot and main studies did score considerably higher than did students in the provincial group. This was done in spite of having the pilot and experimental groups engage in a teaching/learning strategy which required spending considerably more time in the labortory and other non-examination activities.

Table 6 shows the proportion of class time spent on laboratory work by students in the experimental and in a conventional ALCHEM 30 classroom. This was estimated by the investigator who taught ALCHEM 30 using both approaches. Table 6 indicates that students in the experimental study spent over eight hours more time in the classroom and over fourteen hours more homework time on laboratory related activities. These students also spent over five more hours in the laboratory performing four additional experiments.

Attitude Domain

The Test of Scientific Attitude was used to measure student growth in the intent and cognition aspects of scientific attitudes as defined by Nay and Crocker (1970) and Kozlow (1973). Table 7 presents the results of analysis of variance with repeated measures for the pre-and post-test data for the experimental group. This analysis shows that

TABLE 6

Estimated Time Spent by Students in Laboratory Related Work

Activities	*Time Units by ALCHEM Group	*Time Units by Experimental Group
Outline for year's lab work (class time)	1	2
Inventory of Process Skills (class time)	0	2
Safety and Efficiency in lab (class time)	1	1
Lab L1: a. Prelab discussion (class time)	1	2
b. Writing DR and OR (homework)	0	3
c. Writing FR (homework)	3	3
d. Post lab discussion (class time)	1	2
Lab L2	5	10
Lab L3	0	10
Lab M1	5	9
Lab M2	5	10
Lab M3	6	14
Lab M4	0	10
Lab N1	5	9
Lab N2	6	6
Lab N3	0	6
Lab N4	0	8
Total classroom time in units	18	43
Total homework time in units	21	64
Total time in hours	13	35.7

* Each time unit represents a 20 minute period

TABLE 7

Analysis of Variance Summary for Pre-test and Post-test Results for the Test of Scientific Attitudes, TOSA*

	S.S.	D.F.	M.S.	F-RATIO	PROBABILITY
TOSA					
Effects	11.02	1.	11.025	2.510	0.130
Errors	83.473	19.	4.393		

* Results were computed using SPSS Batch System, University of Alberta Computing Services.

although the post-test means for the attitude test is higher than the pretest, the difference in the means is not significant. Hence, it can be inferred that involvement in inquiry-oriented laboratory work has no significant effect on student performance on the cognition and intent aspects of scientific attitude. It should be noted that the TOSA results obtained in the main study are at variance with those obtained in the pilot sutdy where a significant gain was reported (see Table 1).

The TOSA results are perhaps not surprising. The inquiry-oriented laboratory program was not directed primarily toward improving student performance in either the cognition or intent components of scientific attitudes. When a decision was made to use TOSA it was assumed that an indirect influence would be present. This assumption was not supported by the results. The students performed well on the test relative to other reference groups, but did not do well in absolute terms (see Table 4). Students used their knowledge of the cognition component of how attitudes operate in scientific work which they accumulated from various sources during their years of schooling. ALCHEM 30 includes very little that would enhance this knowledge. The intent component of TOSA gets at a more subtle dimension of scientific attitude. The results suggest that before reaching Grade 12 students already are aware of the kind of responses expected in situations involving expressions of scientific attitudes. Apparently neither the ALCHEM 30 course nor the revised laboratory component included sufficient number of situations of the type that might have the impact required by the items in the intent subtest. The inquiry-oriented laboratory program might have an effect on the action component of scientific attitudes, but TOSA was not designed to measure this. Some evidence for the operation (action) of scientific attitudes may be found in the qualitative data to be discussed in the next chapter.

The Process Domain

Student competence in the processes of scientific inquiry as defined by Nay et al (Appendix C) was measured by means of the Processes of Science Test (POST) and the Laboratory Reports.

The Processes of Science Test Results

POST was designed to measure student competence in a variety of process skills as indicated in the "Key for Processes of Science Test" in Apendix F. Table 8 presents the results of analysis of variance with repeated measures for the pretest and post-test data for the experimental group. The results of the analysis show that the difference in the means for POST is significant at the 0.05 level. The probability that the difference in the means could have occurred by chance is less than 0.05. Hence it can be

TABLE 8

Analysis of Variance Summary for Pre-test and Post-test Results for Processes of Science Test, POST*

	S.S.	D.F.	M.S.	F-RATIO	PROBABILITY
POST					
Effects	21.025	1.	21.025	4.729	0.042
Errors	84.477	19.	4.446		

* Results were computed using SPSS Batch System, University of Alberta Computing Services.

inferred that inquiry-oriented laboratory work based on utilization of scientific process skills does have a significant effect in improving student competence in the process domain.

Laboratory Report Results

As was explained earlier, three reports were requried for a laboratory experiment. The means for each student's Design Report, Observation Report and Final Report are given in Appendix O. Table 9 shows the class means for every experiment for each of the three reports. The mean level of performance is approximately 80% on each report, which indicates that students met the inquiry objectives (based on process skill acquistion and utilization) of the laboratory program to a high degree. The non-quantitative aspects of laboratory reporting will be discussed in the next chapter.

Correlation of Results from Quantitative Instruments

The data in Table 10 show the results of calculations of Pearson Product Moment Correlations and the probabilities that they are zero between pairs of quantitative instruments. One interpretation for a high correlation among selected instruments is that they are probably measuring student development in the same domain. The POST instrument is indicated as "process" instrument so as to avoid the use of the label "post-POST."

TABLE 9

Class Means for Design, Observation, and Final Reports for Each Laboratory Experiment

LAB	DR (5 points)	OR (5 points)	FR (10 points)
L1	2.9	3.7	7.1
L2	3.5	4.2	7.0
L3	3.2	4.0	7.3
M1	4.4	4.2	7.4
M2	4.8	4.3	7.2
M3	3.8	3.6	7.6
M4	4.0	3.9	7.7
N1	3.3	3.7	7.3
N2	3.8	3.9	8.0
N3	4.4	4.3	7.5
N4	4.4	4.6	7.7
$\bar{X}$	3.9	4.0	7.4
$\bar{X}$,percent	78	80	74

TABLE 10

Correlations Between Quantitative Instrument Measures

and Associated Probabilities that r=o

	IQ	CHEM 30	Pre TOSA	Post TOSA	Pre Process	Post Process	Lab Reports
IQ	1.00	0.44 (0.026)	0.519 (0.010)	0.69 (0.000)	0.791 (0.000)	0.76 (0.000)	0.46 (0.024)
CHEM 30		1.00	0.15 (0.527)	0.47 (0.035)	0.37 (0.109)	0.41 (0.072)	0.36 (0.121)
Pre TOSA			1.00	0.60 (0.006)	0.46 (0.040)	0.30 (0.206)	0.17 (0.474)
Post TOSA				1.00	0.65 (0.002)	0.50 (0.026)	0.33 (0.155)
Pre Process					1.00	0.76 (0.000)	0.69 (0.001)
Post Process						1.00	0.66 (0.002)
Lab Reports							1.00

a. Probabilities that correlations are zero are given in parentheses below each correlation. (The number of degrees of freedom associated with each correlation equals 18)

b. Processes of Science Test

The I.Q. results correlate rather highly with those from all of the other measures (excluding the Lab Reports), and all of the probabilities are below 0.05. This result is to be expected. The Chemistry 30 results do not correlate too well with the TOSA, POST or Lab Report results. Four of the five probabilities involved are greater than 0.05. This low correlation is also to be expected since the focus in the Chemistry 30 is totally in the conceptual domain of chemistry learning.

The TOSA results do not correlate highly with any of the measures except I.Q. and the post-process with the post-TOSA results. The associated probabilities in these instances are below the 0.05 level of confidence. Generally, these results are to be expected since TOSA measures student performance in a domain different from that measured by other instruments. The rather high correlation between the post-TOSA and post-process measures is rather surprising; although, this may be an indirect consequence of the significantly improved performance in process skill resulting from the inquiry-oriented laboratory program. Many of the TOSA items also involve process skills.

As was expected, the laboratory report results correlate relatively strongly at a high level of confidence with the process (POST) test results, indicating perhaps that both of these instruments give a valid measure of the scientific process skills that students were engaged with in the laboratory. The coefficient of correlations obtained for the relation between these two instruments (r = 0.7) may possibly be even higher for two reasons: (1) According to statistical theory (Hopkins and Glass, 1978, p. 139) the greater the variability among observations, the greater the coefficient of correlation. From Table 4 variances of both tests are relatively low, indicating a restricted correlation. (2) Another factor which can reduce the value of the coefficient is the measurement error. Measurement error on either test "can greatly reduce the value of the observed r" (Hopkins and Glass, 1978, p. 138). Although the measurement error for POST is perhaps as small as for most instruments in the behavioral sciences, measurements made in the Laboratory Reports are largely subjective and are, therefore, suspect. Both arguments above tend to make the r, already relatively high, even higher.

Summary of Quantitative Results

Students in this study, in spite of spending considerably more time in the laboratory and in laboratory related activities than students do in a regular ALCHEM 30 curriculum, were able to successfully compete in the Chemistry 30 Achievement Test, an examination which purports to test objectives at a higher level of cognitive functioning. Although the provincial mean(39.1) is considerably lower than both the pilot (45.5) and the experimental group means (43.6), no claim can be made for statistical significance since the groups could not be equated for intelligence.

In the affective domain pupils did not show any significant increase in performance on the Test of Scientific Attitudes (TOSA), although the post-test means were higher than the pretest.

In the process skill domain the students showed significant gains as a result of the experimental program. The results of the analysis of variance showed that pupils of this study were able to score significantly higher at the end of the school year than at the beginning of the year on the Processes of Science Test (POST). High correlations between the POST results and the marks for the laboratory reports are also supportive of the claim for student gains in the process domain.

Assessing the three domains in the empirical-analytic paradigm with regards to the purpose of this study (Chapter 1), the evidence shows that students were able to attain the majority of objectives in the concept (higher level) and scientific process skill domains but not in the attitude domain. The overall evidence is significant but not overwhelming.

CHAPTER 5

QUALITATIVE RESULTS AND DISCUSSION

In this chapter the qualitative data of this study are reported. These data were collected by means of laboratory questionnaires, written statements, taped interviews, laboratory reports, and teacher's log. All data from these instruments are found in the appendices, but in this chapter only selected data are reported. The data are presented in an integrated manner, and key issues relevant to the laboratory and the inquiry mode of learning are identified. These issues are reported under the concept, process, and attitude domains and follow the discussion on the instruments that were used to collect the data.

Summary of Qualitative Results

Laboratory Questionnaires

In the Laboratory Questionnaires, which were administered within two to three days after every experiment, students were asked pertinent questions about concepts and principles, the process skills, and about their feelings on the laboratory program. The statements on the questionnaires (not the responses) are found in Appendix H. The questionnaires, made up of Likert type statements, required students to respond by indicting whether they (A) strongly agree, (B) agree, (C)[are] neutral, (D) disagree, or (E) strongly disagree with the statements. With 20 students responding to 10 questions on 11 experiments, over 2000 responses were recorded. These responses are reported as percents and are found in Appendix I and summarized in Table 11.

As previously mentioned, there are questions in each domain. Approximately 13% are concept domain questions, 54% are process and 33% are attitude. Slightly more than half of the questions are in the process domain because the study is about inquiry teaching in the laboratory based on process skills. Several questions, however, have been classified in more than one domain, and these domains are identified in Appendix I by the abbreviations Ct, Pr, and At for concept, process and attitude domains respectively. For the sake of manageability all questions were not asked on every questionnaire. Concept, process skill and attitude questions were randomly selected and assigned to a random sample of laboratory questionnaires.

In Table 11, selected statements from all the questionnaires have been grouped under the three domains. In the concept domain students were asked to comment on two specific statements concerning understanding the main background concept of the experiment and whether difficulties were encountered with calculations. These questions were asked for two reasons: (a) to find out how

TABLE 11

Grouping of Laboratory Questionnaire Statements in Each Domain

DOMAIN	QUESTIONNAIRE STATEMENTS (LABS)
Concept	I did not understand the main background concept (L1-3,M1-3,M4,N1-2)
	I had difficulties with calculations or with questions in the interpretations (L1,M1,N3)
Process	1. I had difficulty with the Design Report.(L1-3, M1-2,M4,N1-4)
	2. I had difficulty with the Observation Report. (L1-3,M1-4,N1,N3)
	3. I had difficulty with the Final Report.(L2,M3-4, N1-3)
	4. More guidance should have been provided.(L1-3, M1-4,N1-4)
	5. I had trouble performing [parts of] the experiment.(L2,M2-4,N1-2)
	6. Instructions in laboratory manual were clear. (L1-2,N1)
	7. I believe I can improve my design and technique. (L2)
	8. I felt confident about my determination.(L3,N3, N4)
	9. I believe my process skills have improved.(N2, N3,N4)
Attitude	1. I found the experiment challenging(L3,M1-4,N2-4)
	2. I found this experiment interesting.(M1-4)
	3. I would like more experiments in this unit.(L3, M2,N1)

TABLE 11 (Cont'd)

DOMAIN	QUESTIONNAIRE STATEMENTS (LABS)
	4. I would like to do this experiment again.(L2,N2)
	5. This experiment was not very exciting at the grade twelve level.(L3)
	6. I prefer doing laboratory experiments of this type rather than designing my own experimental steps.(M3)
	7. I would prefer an experiment which has a determination or the answer given.(M4)
	8. I was generally disappointed in my data.(M4)
	9. I was generally pleased with my work in the lab this year.(N4)

well students understood the concepts involved in the experiment, (b) to determine if there were any changes (trends, patterns or growth) in content achievement during the semester. Statements from the process and attitude domains have been similarily grouped.

Written Statements

At the end of each laboratory questionnaire space was provided for students to make written comments. The directive appearing at the end of every questionnaire is repeated here.

> Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

In addition to the above, students were reminded, with each questionnaire, to please include written comments. Students were also reminded that they were part of this study and that their contributions were necessary. During the pilot study students responded well only to the first few laboratory questionnaires, so, in the main study it was decided to encourage students to make written statements by asking them "to explain further" on some questions. These comments are referred to as solicited written comments. Over two hundred written statements on all phases of the experimental program including attitudes and personal feelings are recorded. The majority of the written comments are certainly bona fide; but, no doubt, some students had little to comment about or may not have felt very strongly about parts of the laboratory program and made thereby only token contributions. One can only try to find a general pattern of behavior. A summarized edited list of all written comments are found in Appendix M. Selected groups of written comments are found in Tables 13, 14, 25, 31 and are discussed later in the chapter.

Taped Interviews

Two students, randomly selected, were interviewed after each laboratory investigation. These interview sessions were tape-recorded and each interview lasted approximately thirty minutes. The questions below are those which formed the structured section of the interview. Depending on how students answered the questions, other more in-depth questions were asked.

1. How do you feel about this laboratory investigation? What did you like about it? What features? Why? What did you not care about this investigation?

2. Tell me about your thoughts and feelings on the following:

    (a) the topic investigated. Did you understand the purpose?
    (b) prelab discussions? Were they adequate? Why? (if not)
    (c) design and observation; processing and interpreting data.
    (d) laboratory reports (DR, OR, FR). How do you feel about writing three reports rather than only one?
    (e) marking reports.
    (f) your peers? The teacher? What effect did your classmates and the teacher have on the classroom

setting?

3. How can the laboratory program be improved?

Student responses to the questions on the Taped Interview for each laboratory experiment are found in Appendix L. Compiled results to all responses are included and analyzed later in the chapter.

Laboratory Reports

Although the final marks of the Laboratory Reports were compared with the other quantitative instruments in Chapter 4, the reports have components which need to be investigated in the situational-interpretative paradigm. The reports contain evidence that students exhibited scientifc attitudes which were previously identified in An Inventory of the Affective Attributes of Scientists (Nay and Crocker, 1970). These findings are discussed along with results from the other qualitative instruments.

Teacher's Log

During the Pilot and Main studies records were kept not only of trials, innovations and changes but also of the teacher's feelings, attitudes and interpretations regarding student activites in the chemistry laboratory. As mentioned earlier in Chapter 3 (Experimental Design), field notes of relevant activities, expressions and behaviors were periodically reviewed, condensed and transferred to the Teacher's (Investigator's) Log. In the assessment of the laboratory program the Teacher's Log supplements the other qualitative instruments. Appendix N contains excerpts of some of the more salient notes which were included in the Log.

Analysis of Qualitative Data

The discussions which follow show to what degree students, subjected to the unstructured laboratory experiences of this study, attain objectives in the conceptual, process skill and attitude domains.

Concept Domain

Results of Laboratory Questionnaires. Although the concept domain is treated principally by the empirical-analytic paradigm, there are two questions dealing with this domain in the Laboratory Questionnaires. On the first, students were asked if they understood the main background concept on every laboratory questionnaire except those for Labs M2, N3 and N4. Student responses, found in Appendix I, are summarized in Table 12. The percentages in the table indicate that students believed they understood the main background concept in the majority of experiments. Approximately 76% stated they understood all concepts, while 13% said they did not and 11% were neutral. On the second question dealing with having difficulties with the calculations students were queried about their difficulties on Lab L1, M1 and N3. Using data from Appendix I, student

TABLE 12

Summary of Questionnaire Results

Dealing With Understanding Main Background Concepts

Lab No.	Question No.	Percent Who Understood	Percent Who Did Not Understand	Percent Who Were Neutral
L1	1	65	25	10
L2	2	65	20	15
L3	1	85	0	15
M1	1	95	5	0
M3	7	60	30	10
M4	2	95	0	5
N1	4	65	20	15
N2	1	75	5	20
	$\bar{X}$	76	13	11
	S	13.3	11.7	4.3

views are summarized in Table 13. The summary shows that students were nearly split on the issue: 38% had difficulty with the calculations, 42% did not, and 20% were neutral.

In order to find explanations for the difficulties encountered by students in Labs L1, M1 and N3 the Teacher's Log, the Written Comments, the Interviews, and the Laboratory Reports were searched. Lab L1 was the first lab of the year and the calculations were a bit overwhelming for most students to perform largely on their own for the first time. Regarding Lab M1, a possible clue is found in the Teacher's Log (See Appendix N, Lab M1). The interpretation section of Lab M1 required students to arrange the oxidizing agents (O.A.) and reducing agents (R.A.) in a table of their own design so that their table could be used to "predict" spontaneous reactions. This task was not perceived by the majority of students and only a few were able to suggest a table or a workable scheme. When it was pointed out during the post-lab discussions that the O.A. in a spontaneous reaction is always higher in the table than the R.A. many students said they did not believe they could have discovered that "rule". This important process skill (Conceptualization of Data) was nevertheless discovered by a few students, although their schemes were somewhat complicated.

TABLE 13

Summary of Questionnaire Results Dealing With Having Difficulties With Calculations or With Interpretation Questions

Lab No.	Question No.	Percent Who Had Difficulties	Percent Who Did Not Have Difficulties	Percent Who Were Neutral
L1	10	40	45	15
M1	7	10	65	25
N3	8	65	15	20
	$\bar{X}$	38	42	20
	S	23	21	4

The difficulties encountered in Lab N3 were mentioned by several students in the Written Comment section. In order to calculate the concentration of the ammonia in Lab N3 students had to use results from the previous lab (Lab N2). This fact appears to be the main reason why students felt their calculations were questionable. As one student wrote,

> This lab was not very difficult...results however depended on Lab N2...not very confident about the results

This comment was also expressed by 40% of the class. (See Written Comments, Lab N3 in Appendix M.)

In the student laboratory manual under the interpretation section of Lab N3, students were asked to determine the concentration of ammonia; and they had to answer all the questions on page N52 of the manual. (See Appendix B, Lab N3). On Lab N3 Questionnaire, Number 8, students were required to comment on the following: "I found many of the questions on page N52 difficult." Table 13 shows that 65% of students said they had difficulties. Unlike Lab L1 and Lab M1, in which some guidance had been provided since these were the first experiments in each unit, Lab N3 provided no directions for processing data. Furthermore, the ALCHEM 30 questions on page N52 are difficult. In one of the questions students were asked to determine "the [OH^-] and the pH for the household ammonia used to prepare the ammonia solution for this lab". This involves not only calculating the hydrolysis of a weak base but calculating the concentration of the original solution used to produce this result. Another of the ALCHEM 30 questions asked students to use collision theory to explain a polyprotic reaction. Although this question is related to titrations it has little to do with the purpose of Lab N3.

Results of Written Comments. The concept domain questions deal with (i) understanding the main background concept and (ii) having difficulties with the calculations in the laboratory experiments. The results for both of these questions are found in Tables 14 and 15. At total of approximately 70 written comments were made by students on the issue of understanding the main background concept (See Appendix M). This number of written comments is surprising because students are generally reluctant to make written statements. Furthermore, the issue was mentioned by students on eight of the eleven questionnaires (See Table 14). The issue was no doubt an important one for students, and they felt they should comment upon it.

The results depicted in Table 14 indicate that more students understood the main backgrou[illegible]pt than the number who stated they were confused about the main concept. Since actual written affirmations are perhaps more significant than merely stating percents, a few

TABLE 14

Results of Student Written Comments Dealing With Understanding The Main Background Concept of the Laboratory Experiments

Lab No.	Percent of Class Who Responded	Percent of Class (Responses) Who Understood Main Concept	Percent of Class Who Did Not Understand
Unit L			
L1	50	10	40
L2	20	15	5
L3	70	65	5
Unit M			
M1	35	20	15
M2	35	15	20
M3	5	5	0
M4	25	20	5
Unit N			
N1	60	30	30
N2	25	10	15
N3	10	10	0
N4	0	0	0
$\bar{X}$	30	18	12
S	21	17	13

TABLE 15

Analysis of Written Comments Dealing With Having Difficulties With the Calculations in the Laboratory Experiments

Lab No.	Percent of Class Who Did Not Have Difficulties	Percent of Class Who Did Have Difficulties
Unit L		
L1	10	35
L2	10	15
L3	5	5
Unit M		
M1		
M2		
M3	10	30
M4		
Unit N		
N1		
N2	15	10
N3	*	*
N4		
Possible Responses	100	100
Mean Percent of Possible Responses	10	19

* Although Lab N3 required calculations to arrive at the ammonia concentration, no one admitted in the Written Comments to encountering difficulties with calculations.

representative quotes are listed below. All written comments are in Appendix M.

> This experiment was not too difficult but it expressed much of the principle behind molar heat and was easy to understand. The experiment helped [me] understand molar heat.
>
> ...I would like to re-do the experiment on...[Lab L2] not because I don't understand the principle but because I'd like to better my results.
>
> I felt more confident in doing this experiment because I knew what I was doing and why I was doing it. I learned this from the other labs.

Comparing the overall results of the Questionnaire and the Written comments, on both issues it appears that students generally understood the main background concepts; but on a sample of nearly half the experiments about 20% of the total possible responses in the Written Comments showed that students had difficulties with the calculations (Table 15). On the Questionnaires, the results of the second question, as previously reported on Table 13, showed that 38% had difficulties with the calculations.

Results of Taped Interviews. Table 16 is a summary of student responses of taped interviews taken from Appendix L on Question 2a:

"Did you understand the purpose of the experiment?"

In Table 15 each student response is separated by a double solidus.

Very few students gave negative opinions to Question 2(a). Indeed, of all students who answered the question

TABLE 16

Edited Responses

To Taped Interview Question in the Concept Domain

Questions	Lab	Edited Responses
Did you understand the purpose of this experiment?	L1	At first I didn't know.....Yes, I know now//Purpose was clear. Interesting.
	L2	Kind of interesting...//I didn't see anything practical. Purpose was understood.
	L3	I guess it is interesting to...//It didn't seem too interesting at first--just ice.
	M1	I had trouble understanding what table we were to discover//I understood the purpose.
	M2	I understood the purpose. It was interesting not knowing the species// Purpose was good and I can see the purpose for the table too.
	M3	Yes//Yes, you had to be correct with the primary.
	M4	Yes,...the emf's could be verified experimentally.
	N1	Yes, the purpose was to illustrate everything we studied about redox reactions actually happens; and within certain limitation it did// Yes. Interesting because my predictions and observations were not always the same.
	N2	The purpose was straight forward but difficult...interesting//A good experiment...it took a lot of skills.

TABLE 16 (Cont'd)

Questions	Lab	Edited Responses
	N3	Good, except I was worried about applying my results...//Yes, but this lab more complex [than N2].
	N4	Somewhat vague but the prediction was more interesting and challenging.

* Of the 20 responses, 14 understood the purpose, 2 did not, and 4 were not applicable to the question.

The double solidus separates each student's comments.

only 13% said they did not understand the purpose of the experiments. Regarding the issue of "having trouble with calculations," this question was not asked directly in the interviews; however, Question 2 (c), processing and interpreting data, produced three comments about having difficulties with calculations:

> "...had correct calculations after all." (Lab L2)
> I think we all find calculations difficult." (Lab L3)
> "The calculations were difficult until I caught on." (Lab M3)

Since these comments were not solicited during the interviews, they must be considered as significant.

Results of Laboratory Reports. Laboratory reports also measure the student's ability to understand the background concept of the experiment; otherwise, how can the student know what design to create or what data to collect and process? From Table 9 the overall class means for the DR's show a grade of 78%. In addition, the table shows that the class means for the DR, with few exceptions, are increasing within each of the three units (Units L, M, and N). This increase took place in spite of less guidance by the teacher and the laboratory manual. Furthermore, with the exception of Lab M2, the laboratory investigations were increasing in difficulty as the year progressed. Lab M2 had a more difficult interpretation but the design was very similar to the one in the Lab M1. This issue is discussed further under the process domain.

With regards to "having trouble with calculations," the final reports (FR) show which students processed their data correctly, but there is, of course, no guarantee that students who processed their data correctly had indeed done so without outside help. Table 17 shows the percent of students who made calculation errors in concept for each experiment which required calculations. Regarding the six experiments which required calculations, the table shows that 26% of the class made an error in concept in the calculations. The high percent error made in Lab L2 was a result of students failing to take into consideration that the energy changes involved not only a phase change but also a kinetic change.

Results of Teacher's Log. The Teacher's Log in Appendix N has little to contribute regarding the two issues in the concept domain. As reported earlier, the Teacher's Log shows that for the first few labs at the beginning of the semester students were seeking help with calculations and with the interpretation section of the Final Report. Realizing that help was not forthcoming from the teacher, students fell to their own resources for the remaining experiments. Before students were permitted to go to the work bench the DR had to be completed and handed into the teacher. With the exception of Lab L1, the first experiment

TABLE 17

Results of Laboratory Report Calculation Errors in Concept

Experiments Which Required Calculations	Percent of Class Who Made Concept Error in Calculations	Class Means on FR
Lab L1: Molar Heat of a Chemical Change	20	7.1
Lab L2: Molar Heat of Vaporization	60	7.0
Lab L3: Molar Heat of a Phase Change	25	7.3
Lab M3: Redox Titration	20	7.6
Lab N2: Standardization Titration	15	8.0
Lab N3: Titration - NH_3	15	7.5
$\bar{X}$	26	7.4
S	16	0.3

of the year, students were more apprehensive of what the format of the design should be rather than with the design itself or with problems in the background concept. In Lab L2 (Heat of Vaporization) designs were changed by many students but these changes were trial and error attempts to improve results and not about understanding the main concept. In Lab N4 (Common Ion Effect) the main backround concept was the problem to be discovered.

Summary of Concept Domain Results. The results from the Laboratory Questionnaires, the Written Comments, the Taped Interviews, the Laboratory Reports, and the Teacher's Log suggest that students had few problems understanding the main background concept or the purpose of the experiments, but a significant number of students stated that they found difficulties with calculations. In the next section data in the Process Skill Domain are summarized and discussed and the issue of difficulty with calculations is discussed further.

Process Skill Domain

The design of this study required that the student engage in many more process skills in the laboratory than the number required by students following a regular ALCHEM 30 program. Table 2, shows a comparison of the number of process skills required and the number initiated by students for each experiment. The students in this study purportedly engaged in a high level of inquiry learning, but the key issues in this chapter will be (a) whether students are performing the process skills successfully at a higher level, and (b) whether students perceive their process skills as improving. All the instruments in the situational-interpretative paradigm are used to determine the manner and extent to which students attain the objectives in the scientific process skill domain.

Results From Laboratory Questionnaires. In this section the following questionnaire statements are considered:

1. I had difficulty with the Design Report (DR)
2. I had difficulty with the Observation Report (OR)
3. I had difficulty with the Final Report (FR)
4. More guidance should have been provided by the teacher during the experiment
5. I had trouble performing this experiment
6. The instructions in the laboratory manual were clear
7. I believe I can improve my design and technique in order to minimize the percent error
8. I felt confident about my determination
9. I believe my process skills have improved

Since more data have been collected from the Laboratory Questonnaires than any other instrument, these will be reported in greater detail. Tables 18, 19, and 20, dealing with the first three Questionnaire Statements above, show clearly that students did not perceive the tasks of completing the three reports to be beyond them. The over all weighted means of the responses for the three reports

TABLE 18

Summary of Questionnaire Results
Dealing with Statement No. 1
"I had difficulty with design report"

Lab No.	Question No.	Percent Who Had Difficulty	Percent Who Did Not Have Difficulty	Percent Who Were Neutral
L1	6	25	55	20
L2	1	20	75	5
L3	4	5	95	0
M1	2	15	80	5
M2	3	5	80	15
M3	3	15	80	5
M4	5	5	65	30
N1	2	15	75	10
N2*	-	-	-	-
N3	2	25	65	10
N4	3	5	90	5
	$\bar{X}$	13.5	76	10.5
	S	8	11	9

* The procedural steps (design) were given in the laboratory manual for Lab N2.

TABLE 19

Summary of Questionnaire Results

Dealing With Statement No. 2

"I had difficulty with observation report"

Lab No.	Question No.	Percent Who Had Difficulty	Percent Who Did Not Have Difficulty	Percent Who Were Neutral
L1	8	15	60	25
L2	6	20	60	20
L3	5	0	90	10
	6	5	95	0
M1	4	5	85	10
	5	15	70	15
M2	4	15	70	15
	5	25	65	10
M3	4	20	60	20
M4	6	0	80	20
N1	6	5	75	20
N3	3	10	85	5
	$\bar{X}$	11	75	14
	S	8	12	7

TABLE 20

Summary of Questionnaire Results

Dealing With Statement No. 3

"I had difficulty with final report"

Lab No.	Question No.	Percent Who Had Difficulty	Percent Who Did Not Have Difficulty	Percent Who Were Neutral
L2	7	35	35	30
M3	5	45	20	35
M4	7	10	60	30
N1	5	0	85	15
	7	50	45	5
N2	9	30	60	10
N3	6	25	35	40
	$\overline{X}$	28	49	23
	S	17	20	12

TABLE 21

Summary of Results of

Laboratory Questionnaires Regarding the Laboratory Reports

Reports	Number of Responses	Percent Who Had Difficulty	Percent Who Did Not Have Difficulty	Percent Who Were Neutral
DR	200	14	76	10
OR	240	11	75	14
FR	140	28	49	23
	$\overline{X}$(weighted)	16	69	15

are given in Table 21. The weighted means are based on the total number of responses for each report. From Table 21 the Final Report is seen as one which posed greater difficulty for students than the Design or the Observation Reports. This fact is understandable; since the Final Report required more work by the student than the other reports, it was given greater weight in the evaluation. However, the task of interpreting data in the Final Report should be somewhat the the same regardless of how data are obtained--by following the lab manual or by following one's own design. No special significance, therefore, is attached to the fact that the Final Report was found to be more difficult than the other reports.

Lab Questionnaire Statement No. 4 states: "More guidance should have been provided." The issue of whether students require more or less guidance during an experiment is proportional to the amount of "structuring" provided by the laboratory manual and to the degree of difficulty of the experiment. The question of degree of difficulty, not easy to ascertain, was not asked in the questionnaire. Instead students were asked after each experiment if "more guidance should have been provided." The assumption is made that although the experiments varied in difficulty they all had less structuring than the conventional type and therefore should have been more difficult and required more guidance.

However, students found out after the first laboratory experiment (Lab L1) that they would receive virtually no guidance during the performance of an experiment. The statement on the questionnaire, therefore, is an attempt to determine if students perceived that they could perform these unstructured laboratory exercises without requiring more guidance. The means in Table 22 show that 7% thought more guidance should have been provided, 75% thought not, and 19% were neutral or could not decide. These results are based on 210 responses.

Table 23 is a summary of student responses to Statement No.5: "I had trouble performing (specified section of) this experiment." The results show that on the six experiments 55% of the students did not have trouble performing the task designated, 23% did and 22% were neutral on the issues.

Student responses for the remaining process skill statements (Numbers 6-9) are compiled in Table 24. These questions were grouped together because they deal with the principal process skills necessary in performing an experiment, and they deal with the issue of improving the skills. From the table it can be seen that a large percentage of students felt they were able to improve upon their techniques and designs and felt confident about their determinations. Most students thought the lab manual was clear enough; although, in Lab L1 (See Lab L1, Question 5,

TABLE 22

Summary of Questionnaire Results Dealing With Statement No. 4 "I believe more guidance should have been provided during the experiment."

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
L1	9	10	40	50
L2	8	5	60	35
L3	8	0	85	15
M1	8	15	80	5
M2	7	0	85	15
M3	6	15	65	20
M4	8	5	80	15
N1	9	5	80	15
N2	8	5	85	10
N3	9	10	75	15
N4	8	10	80	10
$\bar{X}$		7	74	19

TABLE 23

Summary of Questionnaire Results Dealing With Statement No. 5 "I had trouble performing (parts of) the experiment."

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
L2	9	20	50	30
M2	8	40	35	25
M3	2	15	55	30
	8	50	35	15
M4	1	15	55	30
N1	8	20	65	15
N2	4	0	90	10
$\bar{X}$		23	55	22

TABLE 24

Summary of Questionnaire Results

Dealing With Statements No. 6 to 10

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral	Number of Responses
6. (Instructions in Manual Were Clear)					
L1	5	50	15	35	20
L2	3	80	0	20	20
N1	1	85	10	5	20
$\overline{X}$		72	8	20	
7. (I believe I can improve my design and technique....)					
L2	10	75	5	20	20
8. (I felt confident about my determination)					
L3	2	85	10	5	20
N3	7	30	35	35	20
N4	2	45	25	30	20
$\overline{X}$		53	23	24	
9. (I believe my process skills have improved)					
N2	2	80	15	5	20
N3	4	90	10	0	20
N4	7	95	0	5	20
$\overline{X}$		88	8	3	

Table 24) only 50% of the students agreed. In the first experiment of the year students perhaps felt insecure about attempting experiments they had to design. In Lab L2, Question 3, 80% said the instructions were adequate. For most students Lab L2 (Molar Heat of Vaporization) was a difficult experiment to obtain a determination with a low percent error, but few students had difficulty designing procedural steps or carrying them out. The difficulties in Lab L2 are discussed later in the Process and Attitude Domains.

The results in Table 24, Statement No. 9, indicate a large proportion of students (88%) agreed with the statement that their process skills had improved. Lab N3 deals with the process skill of reproducibility, and Lab N4 deals with the major process skills of this study: identifying a problem, predicting, designing, hypothesizing, and interpreting data. Lab N4, the last experiment of the school year, required students to exhibit most of the process skills in An Inventory of Processes in Scientific Inquiry. See Lab N4 in Appendix C.

Results from Other Instruments. Data from the remaining instruments in the Process Domain are discussed jointly and are meant to focus on the two key issues: (a) Are students performing higher level process skills, and how well are they doing so? (b) Do students perceive their process skills as improving and what is the evidence?

The Written Comments in the Process Domain are divided into two groups called solicited and unsolicited commments. To some of the questions in the Laboratory Questionnaire students were asked to comment further in the Written Comment section. These comments are referred to as solicited comments and are found in Table 25. The table indicates the proportion of students who responded and the majority opinion of those responses. The unsolicited written comments are primarily in the attitude domain and are discussed later.

The majority opinions of the written comments in Table 25 indicate that students were performing particular process skills at a higher level of inquiry. Lab L2, for example, is considered (by the author) to be one of the more difficult experiments that students had to perform. Several key process skills were required such as: identifying limitation of design as a result of failures, modifying the procedure, repeating the experiment for reproducibility to overcome limitations of intitial design. Table 25 shows that 64% of those who responded in the Written Comments to Question 9, Lab L2 did not believe the experiment was too difficult to obtain a reasonable heat of vaporization. The results of the Laboratory Questionnaire for this question showed that only 20% of the class thought the experiment too

TABLE 25

Summary of Solicited Comments to Questions

Lab No.	Question No.	Solicited Questions	Percent of Class Who Responded	Majority Opinion of Written Responses
L2	9	I believe this experiment is too difficult for me to obtain a reasonable heat of vaporization.	70	Of those who responded 64% thought not and said they could improve results with a different design.
M1	5	I had difficulty in ordering my data so as to identify regularities.	65	Of those who responded 20% agreed.
M3	5	I had difficulty with the FR.	40	About 60% of those who responded agreed.
M4	5	I had difficulty with the DR.	25	Of those who responded 20% agreed.
M4	6	I had difficulty with the FR.	25	Of those who responded 20% agreed.

difficult. Lab M3 was another difficult experiment chosen to see if students could process their data on. Lab M3 requires a multi-operation in calculations. In Part A students were required to calculate the concentration of the permanganate ion from the primary standard ammonium sulfate hexahydrate. In Part B the students then had to use the results of Part A to determine the molar concentration of a hydrogen peroxide solution. On the Lab M3 Laboratory Questionnaire, reported earlier in Table 20, 45% of the class claimed that the FR had been difficult. In the written Comments (Table 25) 60% of those who responded to the solicited question agreed that the FR was difficult. Nevertheless, in the Laboratory Reports the FR results for Lab M3 show that students obtained an average grade of 76% which equalled the mean for the year (Table 9). Therefore, to state on a questionnaire that "I had difficulty with the calculations..." is not necessarily an admission by the student that he did not eventually get the correct answer. Table 17, reported earlier under the Concept Domain, shows that 20% of the class made errors in calculations in Lab M3. Although these were reported as concept errors the percent is considerably lower than the error obtained in the three prior investigations in Unit L (in which on the average 35% of the students made concept errors). Undoubtedly, the data suggest that students perceived their process skills as improving. In addition to the above evidence for this claim provided in relation to Experiment M3, the following statements were made in the taped interviews:

> The calculations were difficult until I caught on. Once the molar concentration in Part A was worked out it was okay.// The interpretations were not difficult once you had the design and observations. Not that hard. I found the design the most challenging in this lab. (See Table 26.)

Furthermore, the evidence in Table 26 shows that students thought the first half of the semester's experiments were more difficult to process and interpret. With the exception of Unit L and Lab N3, students said processing and interpreting data was not difficult to do.

Data from two more questions under the Written Comments in Table 25 remain:

> "I had difficulty with the DR" (Question 5, Lab M4)
> "I had difficulty with OR" (Question 6, Lab M4)

The results in Table 25 show that only 20% of those students who made solicited comments to these statements agreed that they had had difficulties with the reports. These results agree with the Laboratory Questionnaire results previously reported in Table 17.

Interesting results are found in Table 25 with regards to the key issue of performing higher level process skills. Students on the Lab M1 questionnaire were asked to comment further to the statement "I had difficulty in ordering my

TABLE 26

Taped Interview Comments in the Process Domain

QUESTION	LAB	EDITED RESPONSES
Tell me about your thoughts and feelings about processing and interpreting data	L1	Processing data was more difficult. I didn't know what format to use// It was the most difficult part.
	L2	Our percent error was high on first calculation...but we had the right calculations after all//No problem.
	L3	I had trouble with FR//I find trouble with calculations. I think we all do.
	M1	Interpreting is harder [than design or observation]//This lab was easier.
	M2	Interpreting is more difficult// Sometimes processing data can be difficult...in this lab it wasn't too bad.
	M3	The calculations were difficult until I caught on. Once the molar concentration in Part A was worked out it was okay//The interpretations were not difficult once you had the design and observations. Not that hard to do. I found the design the most challenging in this lab.
	M4	Once the design and observations have been done it's easy to do the processing and the interpreting.
	N1	I had no problem and found processing easy//I understood those reactions that agreed with my predictions but I didn't understand why some [reactions] didn't.

TABLE 26 (Cont'd)

QUESTION	LAB	EDITED RESPONSES
	N2	Because we made the designs we knew exactly what to do. I found processing quite easy//I got a very small percent error so I must have been doing some things right. I had few problems with interpretation.
	N3	I had trouble with processing...//I usually have trouble with the interpretations. I don't always know what you want. I don't usually have trouble with the math.
	N4	Processing data was not too difficult for me because the data fitted my hypothesis just the way I predicted.

The double solidus separates each student's comments.

data so as to identify regularities." This important high level process skill is one which ALCHEM and most structured laboratory manuals do not require students to perform since a table or a matrix for recording data is generally provided. On the questionnaire, only 15% agreed that they had difficulty with this skill (Appendix I, Lab M1), and on the solicited written statements 65% of the class responded to the question but only 20% of those agreed. Lab M1 was chosen because it was perhaps more challenging than the other experiments with regard to the process skill in question. The process skill of ordering data in Lab M1 required the student to first distinguish each agent as an oxidizing agent or as a reducing agent then to list the agents in a table or a matrix in order of strength, in such a way so that the table could be used to determine, at a glance, which substances would react spontaneously. The same process skill of "ordering" was queried in the Lab M2 questionnaire (Appendix I, Lab M2, Question 5). Lab M2 is a similar type of experiment to Lab M1 but is more difficult because the reagents were not known to the students (solutions were labelled A, B, C, etc.). On the Laboratory Questionnaire, 25% of the students said they had difficulty ordering data. In the Laboratory Reports the results of the Observation Report (OR) for both experiments showed that students were able to score higher than the year's average

(Table 9).

The Teacher's Log contains reports that students had difficulties with design, ordering and processing data in Lab L1 (Table 79). Difficulties with performing the experiment were reported in Lab L3 (Table 81), and problems in tabulating and organizing data were reported in Lab M1 (Table 82).

Summary of Process Skill Domain Results. The intent of the discussions in this section has been to show that students are successfully engaged in scientific process skills at a high level of inquiry and to show that the students perceived improvements in their process skills. From the Laboratory Questionnaires, data show that 88% of the students in the class believed that their process skills had improved. This evidence was obtained from the last three Laboratory Questionnaires (N2, N3, and N4) (See Table 24). Tables 18, 19 and 20 were used to calculate the percent of the class who had difficulties with the DR, OR, and FR for each unit L, M and N. The results show that there is a gradual decrease in the number of students who had difficulties. These calculations are based on 500 responses from Tables 18, 19, and 20. Although students were performing labs at a higher level of inquiry they were encountering fewer difficulties as the year progressed. From the Laboratory Reports, data show a gradual improvement in achievement for all three reports (DR, OR, and FR) (See Table 10). From the Taped Interviews, data in Table 26 show that as the year progressed students found processing and interpreting easier. From the Written Comments, data in Table 31 (to be depicted later) show that students mentioned they had had difficulties only with the process skills in Lab L1 and L2, the first two of the year. From the Teacher's Log (Appendix N), the data show that only in Labs L1, L3 and M1 did students have difficulties performing the lab and processing data. Further, they requested extra help and guidance only in the first few labs. Evidence recorded in Labs M4, N1, N3 and N4 shows that students experienced a greater number of process skills and became more proficient in carrying them out (See Appendix N: Tables 85, 86, 88, and 89).

The above results from the study coupled with the student gains on POST discussed in Chapter 4 show quite unequivocally that inquiry-oriented learning and teaching is a realistic and attainable objective for chemistry, especially if an inquiry laboratory component based on scientific process skills is included. Students can learn to perform inquiry activities with decreasing difficulty and increasing efficiency, even though the guidance by the teacher and instructional materials is decreased. It is true that the amount of time required to cover a program in an inquiry approach is greater than by conventional means, but the data on the Chemistry 30 Examination discussed in the previous chapter suggest that this does not necessarily result in a penalty on students writing externally prepared content (conceptual) exams.

Attitude Domain

Introduction. As defined earlier in Chapter 1, for purposes of this study, the Attitude Domain includes scientific attitudes as well as feelings that students exhibit, or perceive to have, regarding their participation in the inquiry-oriented laboratory program. The scientific attitudes were evaluated by TOSA and have been discussed in the empirical-analytic paradigm section. In this situational-interpretative section only the attitudes and feelings relative to inquiry-oriented learning are discussed.

Data collected by means of five instruments in this paradigm are recorded and discussed separately. These discussions are then followed by an attempt to focus on key issues which are related to the problem of the study: (a) By what manner and to what extent do students of this study exhibit desirable objectives in the affective domain? (b) How do students perceive the laboratory program? (c) Are the students satisfied with their laboratory work?

Results from Laboratory Questionnaires. The following statements from the Laboratory Questionnaires in the Attitude Domain are discussed in this section:

1. I found this experiment challenging
2. I found this experiment interesting
3. I would like more experiments in this unit
4. I would like to do this experiment again
5. This experiment was not very exciting at the grade XII level.
6. In Part A (Lab M3), fourteen steps were given under Procedure. I prefer doing laboratroy experiments of this type rather than designing my own experimental steps.
7. I would prefer an experiment which has a determination or the answer given.
8. I was generally disappointed in my data.
9. I was generally pleased with my work in the laboratory this year.

The first statement "I found this experiment challenging" was placed on every laboratory questionnaire for students to evaluate except the Laboratory Questionnaires L1, L2, and N1. Table 27 shows that approximately two-thirds of the 160 responses indicate that students found the experiments challenging. Only Lab L3 was found to be "not challenging" by more than 35% of the students. For all other experiments only 5% of the students found them not challenging.

Unit M (Electrochemistry) was randomly chosen for the survey of the question "I found this experiment interesting." The results in Table 28 indicate a high percentage of students (85%) found the experiments in electrochemistry to be interesting. Less than 2% did not

TABLE 27

Summary of Questionnaire Results Dealing With Statement No. 1 "I found this experiment challenging."

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
L3	7	35	35	30
M1	10	25	15	60
M2	10	65	15	20
M3	10	90	0	10
M4	10	70	0	30
N2	10	85	5	10
N3	10	60	0	40
N4	9	95	0	5
$\overline{X}$		65.6	8.8	25.6

The total number of responses for the survey is 160.

TABLE 28

Summary of Questionnaire Results

Dealing With Statement No. 2

"I found this experiment interesting."

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
M1	9	85	0	15
M2	9	75	5	20
M3	9	85	0	15
M4	9	95	0	5
$\overline{X}$		85.0	1.2	13.8

The total number of responses for the survey is 80.

agree with the statement.

The questionnaire results on Statements (3) "I would like more experiments in this unit" and Statement (4) "I would like to do this experiment again" are found in Table 29. The purpose in asking students whether they would like more experiments in the unit is to find out not only whether students enjoy doing the unstructured experiments but whether they enjoy them well enough to want to do more of them. Similarly, asking students whether they would like to do the experiment again is an attempt at finding out whether students care enough about their work to want to do it over in order to get a better result or perhaps to confirm what they got initially. The results for the three labs chosen for the statement "I would like more experiments in this unit" (Table 29) indicate that approximately two-thirds of the 60 responses were in agreement with the statement. Most of the remaining students were neutral on this statement. One is tempted to surmise that to be neutral about high level inquiry laboratory work is to give it tacit endorsation. To Statement (4), "I would like to do this experiment again," Table 29 shows, one more, that approximately four-fifths of all responses were in agreement with the statement. This shows that most students are challenged and motivated to get respectable results in the experiments.

TABLE 29

Summary of Questionnaire Results Dealing With Statements:

(3)"I would like more experiments in this unit".

(4)"I would like to do this experiment again."

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
	(3) "I would like more experiments in this unit."			
L3	10	50	5	45
M2	1	90	0	10
N1	10	55	0	45
$\bar{X}$		65	2	33
	(4) "I would like to do this experiment again."			
L2	5	85	10	5
N2	3	70	7	25
$\bar{X}$		78	7	15

The total number of responses for the survey are 60 and 40 and respectively.

The results for the remaining statements in the Laboratory Questionnaires are grouped and found in Table 30. Since each one was asked only in regard to one experiment, no definitive conclusions can be drawn. The results for Statement (5) indicate that 50% of the students did not agree with the statement and the remainder were neutral. Regarding Statement (6), only 20% of the students preferred to do experiments which had the design steps provided; and the results for Statement (7) are probably not significant since approximately half of the students were divided while the rest were undecided. In fact, students could be reflecting some of the sentiment expressed in Statement 8 which was also based on Lab M4. Experiment M4 was a disappointing one for most students because of the type of voltmeter used to measure the electromotive force of the cells being constructed during the experiment. If a vacuum tube voltmeter (VTVM) is used, acceptable readings are obtained, that is, less than a 10% error is obtained in most cases. However, the student meter with its relatively low internal resistance produces a considerably higher error. Corroded clips, poor connections, contaminated porous partitions (not changing the cotton batting) and other problems are the usual sources of error; however, these errors along with the error incurred by the use of the student meter produced a high percent error for some

TABLE 30

Summary of Questionnaire Results Dealing with the Remaining Statements in the Attitude Domain (5,6,7,8,9)

Lab No.	Question No.	Percent Who Agreed	Percent Who Did Not Agree	Percent Who Were Neutral
	(5) This experiment was not very exciting at the grade XII level.			
L3	3	0	50	50
	(6) I prefer doing laboratory experiments of this type rather than designing my own experiemental steps.			
M3	1	20	55	25
	(7) I prefer an experiment which has a determination of the answer given.			
M4	4	25	30	45
	(8) I was generally disappointed in my data.			
M4	3	55	25	20
	(9) I was generally pleased with my work in the laboratory this year.			
N4	10	80	0	20

students. The original intent for this experiment was to have students initially use the student voltmeter. Only suspect cells would then be checked with the VTVM. There were enough student voltmeters available but, unfortunately, not enough VTVM's, and most students did not find the time to check all the cells with the VTVM. Furthermore, during the Pilot Study students had prepared only four cells and were not rushed while in the Main Study six cells were prepared. As a result, students were unhappy about the data collected. It seems the decision to increase the number of cells for the main study was unwise, especially without providing an adequate number of vacuum tube voltmeters.

For Statement 9, 80% of the students indicated they were pleased with their laboratory work this year, while the remaining 20% were neutral. Whereas the class was generally split in response to questions 5 to 8, the strong positive response to the last question seems to be an unequivocal endorsation of the inquiry-oriented laboratory approach used in the study.

Results of Written Comments. Two questions solicited written comments in the Attitude Domain. In Lab L3 students were asked to comment upon Statement 7: "This experiment was not very challenging." Appendix M, Lab L3, shows that 60% of the class responded with one or more written comments on this issue and of those who responded 30% agreed that the experiment was not very challenging. On the Lab L3 Questionnaire 35% disagreed with the statement and 35% agreed that the experiment was not challenging; but in the written comments these same students who agreed qualified their answers by stating that the experiment helped them "understand principles," "build confidence," and enabled them "to become more efficient." They also thought they should have been given the opportunity to do more experiments in the unit on energy (Appendix M, Lab L3). All students who indicated they were neutral on the questionnaire appeared reluctant to admit that the experiment was challenging although many students said something positive about the experiment.

The last solicited written comment was in response to the Laboratory Questionnaire Lab N4 statement: "How do you like this type of laboratory experiment as a learning experience?" A compilation of all the comments is found in Appendix M. Ninety percent of the class wrote comments, and with very few exceptions the comments were positive. Some were flattering, others were perceptive, and a few were constructive. A few excerpts follow:

> "I knew what I was doing before I went into the lab...."
>
> "I liked the freedom in (design)...."
>
> "You learn more...more challenging...."

A few perceptive ones:

> "I became more aware of what I was doing....maybe actually thinking like a scientist."
>
> "I felt part of the class."
>
> "It forces a person to think."

And some constructive ones:

> "This system should have been started in grade X...."
>
> "I like to modify my design but...(did not always have time)"
>
> "We had to learn from our mistakes."
>
> "I found the labs enjoyable and challenging, especially the titrations."

Table 31 contains an edited list of unsolicited comments mentioned by two or more students. Appendix M, from which Table 31 is taken, contains a summary of written comments for all laboratory experiments. The most often made comments on all questionnaires emphasized that the experiments were enjoyable, interesting, and challenging. Comments were made regarding the usefulness of the Design Report and appear in Labs L1, M3, and N4. These comments ranged from "good idea," "able to change [design]," "gives a better understanding," to "more confident with my own design." (See Table 31). In addition, some revealing comments were made about Lab M3 (Appendix M). Part A of Lab M3 (Redox Titration) provided students with a comprehensive list of procedural steps which enabled students to develop

TABLE 31

Summary of Unsolicited Written Comments

Lab	Edited Comments Mentioned By Two or More Students
L1	"I liked the idea of a design report." "...enjoyable this way." "...more demanding than (ALCHEM 10/20)" "...more guidance needed." "...had difficulty with the calculations."
L2	"I would like to try again and get better results." "...having trouble with calculations."
L3	"I would like to do this lab again." "...interesting lab." "...challenging."
M1	"...challenging." "...easy to do."
M2	"...more challenging than M1." "color tests were confusing." "...interesting." "...difficult to classify the oxidizing and reducing agents."
M3	"...I like to be able to make changes when necessary." "...challenging." "I understand lab better if I have to design it." "...given procedures make you rely too much on the lab manual." "I was not as confident with Part A as I would have been if I had drawn up my own procedures."
M4	"...interesting lab." "...challenging." "The student voltmeter was not very accurate."
N1	"I enjoyed this lab." "...interesting lab because of unexpected results." "I found it difficult to explain the (anomalies)."

TABLE 31 (Cont'd)

Lab	Edited Comments Mentioned By Two or More Students
N2	"I liked this experiment." "...challenging." "...an interesting lab." "The end-point is not easy to arrive at."
N3	"I am not sure of [NH_3] because the [HCl] from Lab N2 is suspect." "...a difficult lab to perform." "I enjoyed this lab." "I had trouble drawing titration curve."
N4	"...interesting labs this year." "...enjoyable." "...challenging." "...more challenging than (ALCHEM 10/20." "This system (of labs) is better although more work." "DR is important...gives a better understanding."

proper titration techniques. Part B, on the other hand, had virtually no steps provided and students were required to design their own. Several students (indeed, 35% of the class) wrote that they preferred to write their own design rather than be given the procedural steps. These written comments were unsolicited comments--students were not asked to specifically comment on the issue. This issue is of such importance that a few original quotations are given here, not the edited versions that appear in Appendix M, Lab M3.

> I would rather invent my own steps because it is easier to remember what to do next. This way I have to keep rereading in my lab.
>
> I prefer to follow steps that may be given to you for the first lab in a new area (unit) where you are doing something totally different. The following labs in that area do not need the written steps but some guidance before the lab is necessary.
>
> It was easier to follow and carry out the ALCHEM procedure (Part A); however, I was not as confident going into the lab as I would have been if I had drawn up my own procedure. I put more thought into the lab if I have to design it.

These results agree with the Laboratory Questionnaire M3, Question I, results (Appendix I), which were reported earlier in Table 30. This table shows that only 20% of the class preferred doing experiments with the design steps given.

Results of Taped Interviews. A summary of student responses to all questions on the Taped Interviews for each laboratory experiment is found in Appendix L. The comments to interview Question 1: "How do you feel about this laboratory investigation?" are varied and add little that is new relative to the Attitude Domain. The most prevalent comment found in the appendix has to do with writing the Design Report. Students thought writing their own design was a "good system". The reasons for doing so varied: "I like being trusted," "more of a challenge," "You have to understand the lab [in order to write your own design]," "Interesting". A few found faults with some of the experiments. Lab N2 was thought to give inaccurate results. In Lab M1, one student thought that the section on electrochemistry had not been properly covered before the lab was attempted. Another, would have preferred more freedom be given him in Lab M2. A few found the calculations difficult in Labs M3 and N3. The above comments with the exception to the one preferring more freedom in Lab M2 were also noted in the Questionnaires and particularly in the special question of Lab N4 in which this same question was asked about all the laboratory experiments. The results of these solicited written comments were very positive (Appendix M, Lab N4, Special Solicited Question).

The results for the remaining questions asked in the Taped Interviews, Questions 2 (a), (b), (c), (d), (e), and (f), are found in Appendix L but summarized in Table 32.

TABLE 32

Results to Taped Interview Question No. 2

"Tell me your thought and feelings on the following."

Question Descriptor	Percent Who Responded	Major Opinion (Percent of Those Who Responded)	
		Understood Purpose	Did Not Understand
2(a) (Topic and Purpose)	95	87	13
		Adequate	Not Adequate
2(b) (Prelab)	95	84	16
		Not Difficult	Difficult
2(c) (Design)	80	88	12
(Observation)	80	94	6
(Processing and Interpreting)	90	56	44
		Prefer Three	Prefer One
2(d) (Lab Reports one or three)	90	94	6
		Fair	Not Fair
2(e) (Marking Reports)	85	70	30
		Complimentary	Not Complimentary
2(f) (Peers)	80	81	19
(Teacher)	80	83	17

Students were asked to give their thoughts and feelings about specific features of the laboratory program and the role students played in this program. The results to the questions are tabulated so that the majority opinion for all labs is depicted. Question 2 (a), (b) and (c) were discussed earlier under the concept domain. Regarding Question 2 (d), the majority opinion of students who responded (94%) said they preferred writing three reports (DR, OR, and FR) rather than a single report as they had been required to do in ALCHEM 10 and 20. Several students mentioned that although writing three reports involved more work it was probably more beneficial to them. There were very few negative comments made on the issue (Appendix L). Responses to Question 2 (e) indicated that the marking was fair although several students thought the teacher had been a stickler for details in some instances.

Responses to Question 2 (f) "What effect did your classmates and the teacher have on the classroom setting?" were tape-recorded by most students without the teacher being present. The majority of comments (over 80%) about peers and the teacher appear as eulogies, particularly those about the teacher. Regarding the eulogies, it is important for the reader to distinguish between the person and the teacher. Considerable evidence in Appendix L, and to some degree in the Teacher's Log, exists to show that the praises lavished upon the teacher were made because of what he did as a teacher--not as a person devoid of teaching. The teacher had placed students in a particular laboratory setting which demanded certain expectations and the students seemingly approved. Praises stated in the Taped Interviews point to specific situations that were created by the teacher. From these situations learning outcomes were produced and have been identified as high level inquiry.

Results of Laboratory Reports. Because of the amount of data involved, the student reports (DR, OR and FR) have not been included in the appendices; however, the reports include evidence for the use of desired scientific attitudes or intellectual adjustments noted in Appendix E. Laboratory reports for the last few experiments showed that students exhibited the action (rather than the cognition or intent) component of such behaviors as objectivity, questionning attitudes, honesty, respect for evidence, and willingness to change opinions. These attitudes were particulary evident in Lab N4, the last experiment of the semester. The experiment was designed to have students identify and exhibit a number of process skills, a large proportion of which were at a high level inquiry ((Appendix B, Lab N4). With little or no assistance from the teacher or the laboratory manual, students were required in the FR to: interpret data by assessing the validity of initial assumptions, predictions and hypothesis; to express the interpretation of data verbally or mathematically; and to state what further evidence was needed to substantiate findings. The examples cited below illustrate the level of achievement in the processes of science but more importantly show that students were also exhibiting desirable attitudes:

1. Predictions were verified but students admitted other observations could not be explained (honesty; respect for evidence).
2. The prediction made said 'nothing would happen', yet students reported conflicting evidence--'a precipitate formed'. (honesty; respect for evidence).
3. Predictions stated that a precipitate of NaCl would form yet no precipitate formed. Upon further re-testing a precipitate formed. (perseverance).
4. The expressed theory fitted the observed facts but students admitted that other tests would be required to verify the hypothesis. 'This experiment will have to be repeated with other [similar] solutions...to see if the same results are obtained.' (suspended judgement; further evidence needed).

Results of Teacher's Log. Most of comments made in the Teacher's Log are observations which belong in the process and concept domains, but several impressions regarding student attitudes are found in Appendix N. At the beginning of the year students expressed preference to working in pairs, but by the fourth experiment the habit of working alone was no longer an issue. Indeed, by the end of the year students seemed to enjoy not only working by themselves but enjoyed being on their own, that is, without requiring guidance from the teacher or the laboratory manual.

Preference for designing their own experiments was exhibited early in the year (Lab N3, Appendix N) but few scientific attitudes were exhibited. These attitudes were not observed until later in the year and especially in Lab N4. Lab M4 in Appendix N showed the need for experiments which yield 'good data.' The respect for evidence and related attitudes were not promoted by this experiment but, as mentioned in the appendix, these attitudes could have been fostered to a much greater degree.

In the titration experiments Labs M3, N2 and N3 students displayed affective behaviors which are those necessary for competence and success in science. Students persevered in attempting to obtain reproducible data. This was especially true in Part B of Lab M3, Lab N2 and Lab N3. However, students were not necessarily motivated intrinsically by these experiments, for they had been challenged by the teacher. This was also true in Lab M4 which was repetitious.

Summary of Attitude Domain Results. Data from a number of instruments was used to determine the manner and extent to which objectives in the Attitude Domain were achieved. As previously stated in Chapter 4, the results from TOSA have not been helpful. However, the qualitative instruments provided a great deal of information on how students felt about the inquiry-oriented laboratory program. The Laboratory Questionnaires, by means of nine statements, covered a variety of topics in the attitude domain. The Written Comments, including six solicited comments, were found on all questionnaire forms. The Taped Interviews, given after each experiment, surveyed every facet of the laboratory program. The Laboratory Reports, required for every experiment, contained selected excerpts on pupils' attitudes. And the Teacher's Log, compiled from field notes, contained records and general impressions about student attitudes on every experiment. The digestion of a multitude of data is quite unmanageable unless a process of selection is used.

One of the issues was to determine how students perceived the laboratory program. In order to give opinions about the present program, students in many cases, made comparisons with laboratory procedures used in previous years, namely those used in ALCHEM 10 and 20. Although students of this study had followed the ALCHEM curriculum (not the alternate program Keys to Chemistry), a direct comparison was never asked of the students.

To the issue of how students perceived the inquiry-oriented laboratory program, a sizable majority of students repeatedly expressed that they found the experiments challenging, interesting and enjoyable. These comments are documented in Appendices I, M, and L and to a lesser extent in Appendix N (Teacher's Log). Students enjoyed the freedom given them in design, and they preferred to design procedural steps rather than be told by the laboratory manual or the teacher. They indicated they preferred to write three laboratory reports (DR, OR, FR) rather than only one; although, they admitted that three involved more work.

The evidence gathered in this chapter suggests that the experiments were enjoyable and interesting because they were challenging. In the original ALCHEM experiments, the challenges are more intrinsic--that is, the authors of ALCHEM had produced a challenging set of experiments. The revised experiments of this study, however, have been made even more challenging because they required students to do their own designing, recording and processing. The members of the class perceived the independent exercise of these process skill requirements as "doing their own thing." As recorded in the Laboratory Reports and the Teacher's Log these requirements produced improvements in pupils' attitudes. This was observed as a gradual process throughout the year.

Perhaps the strongest evidence which supports the claim made about how students perceive their laboratory work is found in the special question in the Written Comments: "How do you like this type of laboratory experiment as a learning experience?" This question, found in Table 77, Appendix M, is not just about Lab N4 but about the type of experiments the students had been performing all year. Almost every student answered this question by comparing the unstructured labs of the Revised ALCHEM with experiments performed in previous years. A Hawthorne effect may have been operative, partly because students were aware that they were involved in a study, but the students preferred the experiments used in this study.

CHAPTER 6

SUMMARY, IMPLICATION, AND FURTHER RESEARCH

Summary of the Study

This study attempted to assess the impact of inquiry-oriented laboratory work on students in Grade 12 chemistry in Alberta. It addressed several questions, most notably the following:

1. To determine the manner and extent to which students who are presented with minimally structured (directed) laboratory experiences are able to attain objectives in the domains of concept learning (higher level), scientific attitude and scientific process skills.
2. To determine how students "feel" about learning chemistry in which inquiry-oriented laboratory work is emphasized.
3. To delineate teaching strategies to be employed by the classroom teacher for the effective use of an unstructured laboratory component in a chemistry course.

To answer the above questions it was deemed necessary to collect both quantitative and qualitative data, the first by means of an empirical-analystic paradigm and the second by means of a situational-interpretative one. The research methodology, instructional materials and data collecting methods were developed, tested and refined during a pilot phase involving three Chemistry 30 classes (54 students) in two separate school semesters. The sample for the main study consisted of one class of Chemistry 30 (20 students) which was engaged in the inquiry-oriented laboratory for a full school semester.

The displays or instructional materials used in the study consisted of eleven experiments, eight of which were from the prescribed ALCHEM 30 program but revised to a higher level of inquiry, while three were added by the investigator. These experiments were based on an inventory of scientific process skills (Nay et al, 1971), and the level of inquiry was defined by the number of process steps which had to be initiated by the student rather than by the teacher or the manual. Sixty-five per cent of all the steps in the eleven experiments (more than double the number in the original ALCHEM 30 experiments) had to be initiated by the student, attesting to a high level of inquiry.

The laboratory work was performed by students as part of the regular Chemistry 30 program, but required about three times the amount of time (in class, during breaks and homework) that would have been spent on the original ALCHEM 30 experiments. However this time was obtained mainly at the expense of activities found in a traditionally-taught course.

The quantitative instruments used in the study were as follows: Chemistry 30 Achievement Examination (Alberta Education, 1979); Processes of Science Test, POST (BSCS, 1962); Test on Scientific Attitudes, TOSA (Andruski, Kozlow and Nay, 1981); Laboratory Questionnaires, and three Laboratory Reports, namely the Design Report (DR), the Observation Report (OR) and the Final Report (FR). The qualitative data came from the Laboratory Questionnaires, written comments in the Laboratory Questionnaires, the three Laboratory Reports, Taped Interviews, and Teacher's (Investigator's) Log.

Summary of Quantitative Results

The Chemistry 30 Achievement Test, the main instrument in the concept domain, was used to answer two questions: (1) Do students subjected to the laboratory experiences of this study attain objectives at the higher level in cognitive domain? (2) What effect does the additional time required on inquiry objectives have on the student's concept achievement? In Chapter 4 it was established that the Chemistry 30 Test was testing students at the higher levels Bloom's taxonomy of educational objectives in the cognitive domain (1956). Over 50% of the questions in the instrument are purported to be of the application, analysis, and synthesis type. The remainder consisted of questions in the knowledge and comprehension categories (Table 3). The achievement test results showed that students of this study were able to successfully compete with students from the provincial group. However, no rigorous statistical claims are made to show that students of this study did significantly better than the provincial group.

The Test on Scientific Attitude (TOSA) was used to measure scientific attitudes such as objectivity, open-mindedness and questioning attitudes (Appendix G). TOSA consists of two sub-tests: the cognition one measuring student's knowledge of how scientists behave attitudinally while performing research, while the intent sub-test measures students' attitudinal intent when presented with various attitudinally-loaded situations. This instrument failed to show any significant change when administered as a pretest and post-test; this result is inconsistent with the results from all of the other instruments. The cognition sub-test of TOSA is probably not a valid instrument for this study. No where in the core, elective, or laboratory materials of the ALCHEM 30 curriculum are students given materials or topics related to the scientific attitudes that scientists should have, nor were attitudes emphasized in the classroom or in the laboratory during the year. On the other hand, there was some scope for the intent component to develop in the inquiry-oriented laboratory work. However, no attempt was made to isolate and analyze the intent sub-test results.

The analysis of variance with repeated measures for the pretest and post-test for the Processes of Science Test (POST) was significant at the 0.05 level. Students were able to attain the process skill objectives tested in POST during the main study. These objectives are as follows:

1. Recognize adequate criteria for accepting or rejecting hypotheses.
2. Prepare experimental designs for solving a problem.
3. Attend to controls, adequate sampling and careful observation.
4. Appraise and interpret data.

The overall results obtained on the basis of the empirical-analytic paradigm suggest modest claims in cognitive development and process skill acquisition as a result of students' engagement in inquiry-oriented laboratory work.

Summary of Qualitative Results

In Chapter 5 under the concept domain, the results from all qualitative instruments showed that students had few problems understanding the main background concepts or the purpose of the experiments (Tables 10, 11, 13, 15), but results showed that students had difficulties with calculations (Tables 12, 14 and 16).

In the process skill domain, Tables 17 to 26 show (a) that students were performing satisfactorily a greater number of skills and at a higher level of inquiry than those involved in the original ALCHEM experiments, and (b) that students' scientific process skills had improved throughout the year.

Results in the attitude domain strongly support the following conclusions:

1. Students exhibited important positive attitudes towards inquiry-oriented laboratory work (Tables 29-32 and Appendices E,L,M, and N).
2. Students perceived their work to be well done and were satisfied with their laboratory performance (Tables 29, 30, 32 and Appendices M and N).
3. Students found the experiments challenging and interesting (Tables 27, 28, 31 and Appendix M).
4. Students enjoyed their laboratory work (Tables 31, 56, 58, 64-67, 72, 74-78, and Appendix N).

Other less substantiated conclusions were as follows:

1. Students preferred designing their own experimental procedures rather than being told what to do (Table 30).
2. Students would have liked to do more experiments in each of the units of the study (Table 29).
3. Students preferred writing the three reports rather than only one because they perceived important pedagogical

benefits and believed the reports were marked fairly (Table 32).

4. Students thought the teacher was contributing strongly to the success of the laboratory program (Tables 32, 56 to 66).
5. Students by the end of the semester enjoyed being on their own while performing experiments (no longer wishing to work in pairs) and required little guidance from the teacher or the laboratory manual.
6. Students did exhibit in their laboratory work scientific attitudes such as "honesty" and "respect for evidence."

The degree of "certainty" regarding the above inferences and conclusions is variable, depending upon the number of experiments and instruments that were used to collect the data underpinning them.

Summary of Discussion of Results

The main purpose of the study is about inquiry teaching in the laboratory and its effect upon student performance in terms of (a) concept acquisition and application, (b) scientific process skill competence, and (c) display of scientific attitudes in experimental work and positive attitudes towards inquiry learning in the laboratory. Findings in each domain are summarized separately below.

Concept Development. The Chemistry 30 Achievement Test purportedly tested the higher level cognitive skills. Although it was not possible to show that pupils had improved in concept acquisition and ability to deal with course content at higher cognitive levels, it was possible to show that student performance in this domain did not suffer in spite of the extra time spent on inquiry. This finding contradicts the criticism that inquiry teaching is inefficient for learning because too much time is spent on introducing, developing, and practicing the processes of scientific inquiry, causing concept development and subject matter asquisition to suffer (Ausubel, 1968).

The final marks in the three laboratory reports, especially in the DR and Fr, indicate students understood the concepts involved. However, the correlation between Lab Reports and the Chemistry Achievement Test was found to be 0.36 (Table 8). This low correlation is probably an indication that the Achievement Test is not measuring areas directly related to the laboratory work, since no questions on experiments were included in this test.

The data indicate that students encountered problems in the concept domain, not all of them being totally resolved. In particular, students had difficulty with experiments requiring mathematical calculations. An average of 20% of the students professed this difficulty in the Laboratory

Qeustionnaires. However, the Laboratory Reports showed that an average of 26% of the class made calculation errors. This indicates that this aspect of the experimental work needs to be more guided especially in the initial stages of the laboratory program and in regard to experiments involving a difficult concept (e.g., Lab L2).

Process Skill Utilization. In earlier chapters it was argued that the teaching strategies employed in this study were considered to be at a high level of inquiry. Inquiry was defined in terms of scientific process skills with the level being dependent on the relative number of skills that had to be initiated by the student (Appendix A). The utilization of process skills was controlled in the main by the Revised ALCHEM 30 Experiments and the requirements of three laboratory reports. By listing the procedural steps in the Design report (DR) before going to the work bench on lab day, students had to demonstrate that they understood not only the purpose of the experiment but the manner in which the problem was to be solved. The Observation Report, to be completed before the end of the period, indicated to the teacher not only if data were correctly recorded but if students understood what data were needed. Most importantly, the data had to be consistent with the DR. The Final Report, the most difficult report for students, had to show how data were processed and how well the purpose of the experiment had been achieved.

All of the instruments except the Chemistry 30 Achievement Test and TOSA contributed data which showed that students were able to perform the necessary scientific skill at a high level of inquiry. Data from both research paradigms in this domain have produced results which are complimentary. Not only were students able to perform the necessary process skills but as the year progressed these skills were observed by the teacher and perceived by the students as improving.

Display of Positive Attitudes. The five qualitative instruments produced data which indicate the display of positive attitudes by students towards the inquiry-oriented laboratory program. The majority of students found the experiments challenging, interesting and enjoyable. The majority of students expressed approval with almost every facet of the laboratory program: prelab sessions, designing, ordering, processing, writing reports (DR, OR, and FR), and marking reports. Upon comparing the type of laboratory experiment with experiments from previous years, students of this study were unanimous in stating their preference for the lesser guidance provided in the experiments used in this study.

Pretest and post-test results of TOSA failed to measure significant improvement in the acquisition of scientific attitudes. This may be primarily attributable to the lack of concentration on elements in the inquiry-oriented laboratory work which could improve student performance on the test. In the Kozlow and Nay model (1976), three components of scientific attitude are defined: cognition, intent, and action. TOSA purports to measure only the first two components. Kozlow and Nay claim that the action component must be assessed in the classroom or laboratory. Because of inherent difficulties, no attempt was made in this study to evaluate the action component rigorously. However, it is the belief of the investigator that the inquiry nature of the experiments and the teaching strategy employed in the laboratory program of this study have helped students to develop the following attitudes:

1. Appreciation for research methods:
    - (a) Students experience the difficulty of design, collection of data and interpretation of results.
    - (b) Students know that data collected with good precision are easier to process and lead to more meaningful results.
    - (c) Students begin to prefer quantitative to qualitative results.
2. Independence:
    - (a) Students learn to act on their own when asked to design experiments and classify, order and data.
    - (b) By not being able to seek aid from the teacher students learn to solve problems on their own.

3. Courage:

   (a) Students develop the attitude of not being afraid to make decisions which may lead to mistakes.

   (b) Making errors is accepted as a part of investigative activity and a valuable way of learning.

4. Confidence:

   (a) Students develop confidence in their own problem solving abilities (e.g., by being required to hypothesize, make predictions and design experiments).

   (b) In the post lab discussion periods students become increasingly more willing and competent to argue and defend their positions on the laboratory reports.

5. Respect for evidence:

   (a) Students gain the realization that in the interpretation section of the lab report the explanations must agree with design and observations.

   (b) Statements had to be supported with facts.

6. Interest in science:

   (a) Because of the greater freedom provided, students become more involved.

   (b) By finding experiments challenging, enjoyable and interesting, interest in science is enhanced.

Conclusion

This study has shown that students who participated in high level inquiry while in the laboratory were able to satisfactorily exhibit specific content and concept development, a variety of scientific process skills and some desirable attitudes. These findings reflect a reality which Sanders and Schwab (1979) describe as complex and subtle, and which requires a combination of complementary research paradigms to understand it adequately. Consequently, two research paradigms were chosen for this study. The empirical-analytic paradigm provided valuable information but was not designed to allow the subtle and complex nature of human behavior to be recorded and evaluated. It was the situational-interpretative research mode that provided information on the varied meanings, intents and attitudes that students experience in the educational process. Behaviour patterns were sought to understand the reality experienced by students in learning situations involving the laboratory. Some of these patterns resulted from the purpose of the chemistry program as modified for the study, while others were not so "preordained." A situational-interpretative research paradigm must be sensitive to pick up both anticipated and unpredictable student responses. Evidence presented in Chapter 5 indicates that both types of student behavior were amply monitored.

Within a given paradigm there is a need to give attention to the validity and reliability of findings. Perhaps the easiest way to attend to this matter is to use more than one source of evidence for a given parameter. For this reason it was decided to use several distinct data-collecting modes for each domain of concern in the study. The one exception, the use of a single instrument (TOSA) to measure scientific attitudes, demonstrates the wisdom of using multiple data-collecting channels. The pre and post-test results on TOSA showed significant student growth in the pilot study but not in the main one. As a result the actual impact of inquiry-oriented laboratory teaching on scientific attitude of students remains to be determined.

The study provides considerable evidence for student growth in use of scientific process skills, including manipulation of laboratory equipment. However, evidence of student growth in functioning at an increasing level of inquiry is not as clear cut. Data has been provided by means of the qualitative instruments which lead one to infer that indeed the students functioned with increasing ease at higher levels of inquiry as they progressed through the eleven experiments. Despite the evidence cited, there is a need for more definitive studies to settle this issue.

However, because of the complexity of the learning process, research may never be able to show convincingly that laboratory experiences of the type used in this study are responsible for achieving significant learning outcomes. But until the learning process is better understood, the science teacher can only continue to believe that the unique experiences of the inquiry-oriented laboratory are worthwhile. Studies such as the one described above give credible support to such a belief.

This study also provides some practical directions for inquiry-oriented teaching based on laboratory activity. The teaching/learning strategies used are not the only ones possible, but if results similar to those obtained by the students of this study are desired, then the following suggestions must be considered:

1. Early in the year students should be introduced to scientific process skills by means of a model such as the Inventory of Processes in Scientific Inquiry (Nay et al, Appendix C). Students need to be familiar with the major tenets of such an inventory and the relationship the processes will have with the experiments to be preformed.
2. If the experiments in the original laboratory manual are highly structured, then some of the procedural steps in the manual must be removed and not be made available to

students. Depending on the philosophy of the teacher, new experiments may be necessary. The following guidelines are useful in determining what procedural steps (process skills) should be left to the student to initiate: (a) For the first experiments of the year, more guidance and structure are necessary; but as students become familiar with techniques and gain confidence guidance and structure are reduced. (b) Students should be encouraged to attempt unorthodox designs, even designs which the teacher suspects will fail. Let students learn from their mistakes. Providing a helpful hand or a hint in order to save time or avoid trouble later does not permit students to learn from their mistakes. (c) Ready-made tables should never be made available and students should be encouraged to collect, order, classify, and tabulate data even early in the year. With experience students do not find these tasks difficult.

3. Evaluation of the laboratory work should focus on how students attempt to answer the problem based on their stated designs and not on the percent error obtained. Although accuracy is always an important consideration, it should not be the main one in this type of inquiry.
4. Every experiment has open-ended possibilities and students should attempt the open-ended exercise after

gaining the requisite conceptual and experimental background in such process skills as designing, ordering and tabulating.

The prescribed laboratory manual should never become the "text" which must be diligently followed. The innovative teacher has few qualms about modifying, supplementing or eliminating existing procedures. To have students follow the highly structured laboratory manual to the letter is perhaps easier for both students and teacher but only the "appearance, but not the reality, of enquiry is provided" (Schwab, 1964).

Implications for the Science Teacher

1. The study shows that students can become independent inquirer in a laboratory program. They will need suitable instructional materials, a coherent problem-solving model such as the Inventory of Processes in Scientific Inquiry (Nay et al, Appendix C), and a teacher who is knowledgeable about inquiry teaching and learning and committed to this approach. Also adequate operational conditions must be provided (e.g., manageable class size, scheduled time for laboratory work, adequate laboratory facilities, and time for the teacher for setting up the lab and marking).
2. Emphasis on inquiry-oriented laboratory work need not penalize student achievement on external exams in which

only the conceptual domain is evaluated.

3. Students are more motivated to work in an inquiry program because they find it more interesting and challenging.
4. Students engaged in a chemistry course with emphasis on inquiry-oriented laboratory activity gain a better understanding of and feeling for the nature of chemistry than is provided by a didactic teaching approach.

Recommendations for Further Research

A number of significant questions are stated below which need to be researched, and very likely each question will require a multi-paradigmatic approach.

1. Can the approach used in this study be used equally effectively in other grades and scientific disciplines?

2. How does the ability level of the students in the class relate to the specific strategies used in inquiry-oriented laboratory work and to the effectiveness of this approach?

Some writers have suggested that only gifted students benefit from an approach such as was used in this study. Other researchers claim that laboratory work is often a waste of time.

3. How should the science program be modified so that the action component of scientific attitude receive more directed emphasis?

Clearly the action component of scientific attitudes is the most important of the three identified by Kozlow and Nay (1976). It is necessary to determine ways of consciously incorporating ways of enhancing this component and assessing it comprehensively. Rigorous evaluative instruments must be developed for the valid assessment of scientific attitudes in action.

4. What is the effect on pupil attitudes, process skill utilization and concept development if students in an inquiry laboratory program are permitted to work at their own pace?

5. What are the significant pupil-teacher and pupil-pupil interactions in inquiry-oriented teaching activity?

More research is needed to determine what happens during the three phases of laboratory work. This would cover such dimensions as the nature of teacher guidance, the difficulties encountered by students, how the nature of the difficulties and guidance affect student attitudes towards inquiry-oriented laboratory work, and the role of competition and cooperation.

6. What are the outcomes in the domains of pupil attitudes, scientific process skill utilization and concept development if all aspects (not only the laboratory phase) of a science course are inquiry-oriented?

Research on this question could also address such aspects as the effectiveness of each mode of teaching for development of competence in using scientific process skills, the optimum amount of time to be spent on laboratory activity, and student preferences for approaches in learning science.

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APPENDIX A

SCIENTIFIC PROCESS SKILL ANALYSIS OF ALCHEM 30 AND REVISED EXPERIMENTS

TABLE 33

Lab, L1 MOLAR HEAT OF A CHEMICAL CHANGE

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	Mass, vol., temperature
(c) making assumptions	M	M	All solutions=1.0 g/mL
(d) delimiting problem	T	T	Calorimeter losses are ignored
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	M	ALCHEM 10 and 20
(b) doing literature research	M	M	Class notes, library
(c) consulting people	T	T	
3. PREDICTING	M	M	
4. HYPOTHESIZING	M	M	
5. DESIGNING COLLECTION OF DATA			(Must complete DR before going to the lab bench)
(a) defining variables	M	S	choose acid, initial temp.
(b) defining experimental steps	M	S	Students do all
(c) equipment and techniques	M, T	M	prelab and ALCHEM
(d) safety	T	T	
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	
(c) modifying procedures	T	T	
(d) repeating experiment	T	T	Told to do so
(e) recording data	M	S	Table not provided
7. OBSERVING AND OBSERVATIONS			OR must be completed before end of lab period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	
(d) graphical data			Not necessary
(e) serendipity	S	S	Opportunity provided
(f) accuracy of data	M	S	
(g) reliability and validity	M	S	
8. ORGANIZING THE DATA			
(a) ordering	M	S	
(b) classifying	M	S	
(c) comparing	S	S	Students compare each others'

TABLE 33 (Cont'd)

Lab L1

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			Students decide which results to use
(a) calculating	M	M, S	
(b) using statistics	M	T	(test of significance provided)
(c) uncertainty of results	M	M	
11. INTERPRETING THE DATA			
(a) explanation of data	M	M	
(b) generalization or inferences			
(c) assessing validity of predictions	T	T	
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal	M	M	
(b) mathematical	M	M	
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY	T	T	
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence	T	T	
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables	T	T	Different acid, base, and concentration suggested
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE	T	T	
TOTAL NUMBER OF SUBSKILLS	39	39	
INITIATED BY STUDENT	7	16	

TABLE 34

Lab L2 MOLAR HEAT OF VAPORIZATION

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING	*		*This lab is not included
A. PROBLEM			in ALCHEM 30
(a) speculating		M	
(b) identifying variables		M	Initial volume of water
(c) making assumptions		M, T	
(d) delimiting problem		T	Phase and K.E. changes
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences		T	Meaning of phase change
(b) doing literature research		M	
(c) consulting people		T	
3. PREDICTING			
4. HYPOTHESIZING		T	
5. DESIGNING COLLECTION OF DATA			(DR must be completed before going to work bench)
(a) defining variables			initial temp, mass of H_2O
(b) defining experimental steps		S	Students design all steps
(c) equipment and techniques		T	
(d) safety		T	Steam burns discussed
(e) method for recording data		S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus		S	
(b) performing experiment		S	Work in pairs
(c) modifying procedures		S	Trial and errors to improve-
(d) repeating experiment		S	Several repeats -results
(e) recording data		S	Designs table
7. OBSERVING AND OBSERVATIONS			(OR must be completed before
(a) qualitative data		S	end of lab period)
(b) quantitative data		S	(Students experience
(c) gathering specimens		S	many failures)
(d) graphical data			
(e) serendipity		S	
(f) accuracy of data		S	(High percent error due to
(g) reliability and validity		S	transfer of condensed steam
			instead of steam)
8. ORGANIZING THE DATA			
(a) ordering		S	
(b) classifying		S	
(c) comparing		M	

TABLE 34 (Cont'd)

Lab L2

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating		S	(Many students fail to consider the K.E. change along with the phase change)
(b) using statistics			
(c) uncertainty of results		S	
11. INTERPRETING THE DATA			
(a) explanation of data		S	(High percent error obtained for those who made error in concept)
(b) generalization or inferences		S	
(c) assessing validity of predictions		S	
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal		S	
(b) mathematical		S	
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS		34	
INITIATED BY STUDENT		23	

TABLE 35

Lab L3 MOLAR HEAT OF PHASE CHANGE

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	S	Mass of ice
(c) making assumptions	M, T	M, T	Phase and K.E. change
(d) delimiting problem			considered
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	M	
(b) doing literature research	M	M	
(c) consulting people	T	T	
3. PREDICTING	M	S	
4. HYPOTHESIZING	M	S	(DR had to be completed before going to the work bench)
5. DESIGNING COLLECTION OF DATA			
(a) defining variables	M	S	
(b) defining experimental steps	M	S	Designs all steps
(c) equipment and techniques	M	S	(Many brought or constructed
(d) safety			their own calorimeters)
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	Works individually
(c) modifying procedures		S	Few changes
(d) repeating experiment		S	Several times for-
(e) recording data	M	S	-reproducibility
7. OBSERVING AND OBSERVATIONS			
(a) qualitative data	S	S	(OR had to be completed before end of period)
(b) quantitative data	S	S	Few difficulties encountered
(c) gathering specimens	S	S	
(d) graphical data			
(e) serendipity		S	
(f) accuracy of data	M	S	Good accuracy obtained
(g) reliability and validity	M	S	
8. ORGANIZING THE DATA			
(a) ordering	M	S	Similar to Lab L2
(b) classifying			
(c) comparing			

TABLE 35 (Cont'd)

Lab L3

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			(Most students do not repeat the same concept error as in Lab L2)
(a) calculating	M	S	
(b) using statistics	M	T	
(c) uncertainty of results	M	S	
11. INTERPRETING THE DATA			
(a) explanation of data	M	S	(The class percent error is about 8.5%)
(b) generalization or inferences			
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			Students distinquish between heat of reaction and molar heat
(a) verbal	M	S	
(b) mathematical	M	S	
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	33	36	
INITIATED BY STUDENT	6	29	

TABLE 36

Lab M1 ELECTROCHEMISTRY - AN INTRODUCTION TO REDOX

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	Metals, meltallic ions
(c) making assumptions	M	M	
(d) delimiting problem	M	M	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	M	
(b) doing literature research	M	M	
(c) consulting people	T	T	
3. PREDICTING	M	S	(Many students predict a metal would not react with its own aqueous ion)
4. HYPOTHESIZING	M	M	
5. DESIGNING COLLECTION OF DATA			(DR had to be completed before going to the lab bench)
(a) defining variables	M	S	Metals and ions
(b) defining experimental steps	M	S	Defines all steps
(c) equipment and techniques	M	M, S	
(d) safety	T	T	
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	Works individually
(c) modifying procedures		S	Few problems
(d) repeating experiment			
(e) recording data			Tables not provided
7. OBSERVING AND OBSERVATIONS			(OR had to be completed before end of lab period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	(Few difficulties encountered)
(d) graphical data			
(e) serendipity			
(f) accuracy of data			
(g) reliability and validity			
8. ORGANIZING THE DATA			
(a) ordering	M	M	
(b) classifying	M	M	
(c) comparing	M	M	

TABLE 36 (Cont'd)

Lab M1

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating			
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			
(a) explanation of data	M	S	(Few students can order their data so as to be able to predict a spontaneous reaction)
(b) generalization or inferences	S	S	
(c) assessing validity of predictions	S	S	
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal			
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	26	27	
INITIATED BY STUDENT	8	15	

TABLE 37

Lab M2 ELECTROCHEMISTRY - SPONTANEOUS REACTIONS

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING	*		
A. PROBLEM			*This experiment is not included in ALCHEM 30
(a) speculating		M	
(b) identifying variables		M	(Reagents were labelled algebraically A, B, C, and X, Y, Z)
(c) making assumptions		M	
(d) delimiting problem		T	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences		S	Experiences from Lab M1
(b) doing literature research		S	ALCHEM notes
(c) consulting people		S, T	Color tests were provided
3. PREDICTING		S	
4. HYPOTHESIZING		S	
5. DESIGNING COLLECTION OF DATA			(DR had to be completed before going to work bench)
(a) defining variables		S	Reagents were unknown
(b) defining experimental steps		S	Defines all steps
(c) equipment and techniques		S	
(d) safety		T	
(e) method for recording data		S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus		S	
(b) performing experiment		S	Works individually
(c) modifying procedures		S	Few changes
(d) repeating experiment		S	Only when anomalies arose
(e) recording data		S	
7. OBSERVING AND OBSERVATIONS			(OR had to be completed before end of lab period)
(a) qualitative data		S	Students found the color tests confusing
(b) quantitative data		S	
(c) gathering specimens		S	
(d) graphical data			
(e) serendipity			
(f) accuracy of data			
(g) reliability and validity			
8. ORGANIZING THE DATA			
(a) ordering		S	(Once the reagents were classified as OA and RA classifying was similar to Lab M1)
(b) classifying			
(c) comparing			

TABLE 37 (Cont'd)

Lab M2

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating			
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			
(a) explanation of data		S	The relative strengths of OA and RA were obtained from ordered data
(b) generalization or inferences		S	
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal		S	
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY		S	(The relationships found in Lab M2 were applied to this experiment)
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence		T	
(b) test generalizability		T	
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables		T	
(b) unexpected observations			
(c) inconsistencies in theory		T	Other species tested (Mg & Br_2) appeared to be inconsistent
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS		33	
INITIATED BY STUDENT		23	

TABLE 38

Lab M3 REDOX TITRATION

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M, S	(Concentration of MnO_4^-
(c) making assumptions	M	M	from Part A)
(d) delimiting problem			
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	S	
(b) doing literature research	M	M	
(c) consulting people	T	T	
3. PREDICTING	M	M, S	
4. HYPOTHESIZING	M	M, S	(DR--Part B only--had to be completed before going
5. DESIGNING COLLECTION OF DATA			to work bench. Part A
(a) defining variables	M	S	design was given)
(b) defining experimental steps	M	S	Defines all steps in Part B
(c) equipment and techniques	M	M, S	Similar to Part A
(d) safety	M, T	M, T	
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	Works individually
(c) modifying procedures		S	
(d) repeating experiment	M	S	Repeated at least 3 times
(e) recording data	S	S	Tables not provided
7. OBSERVING AND OBSERVATIONS			(OR had to be completed
(a) qualitative data	S	S	before end of lab period)
(b) quantitative data	S	S	(Buret readings, not
(c) gathering specimens	S	S	volumes, had to be
(d) graphical data			recorded)
(e) serendipity			
(f) accuracy of data			
(g) reliability and validity	S	S	
8. ORGANIZING THE DATA			
(a) ordering	M	S	
(b) classifying	M	M	
(c) comparing			

TABLE 38 (Cont'd)
Lab M3

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			Stoichiometry was difficult for some students
(a) calculating	M	M	
(b) using statistics	M	M	
(c) uncertainty of results			
11. INTERPRETING THE DATA			(Lab manual stated what data had to be processed)
(a) explanation of data	M	M	
(b) generalization or inferences	M	M	
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal	M	M	
(b) mathematical	M	M	
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	32	32	
INITIATED BY STUDENT	8	19	

TABLE 39

Lab M4 ELECTROCHEMICAL CELLS

Key: S= initiated by student, T= guidance provided by teacher and M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	
(c) making assumptions	M	M	
(d) delimiting problem	M	M	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	M	
(b) doing literature research	M	M	
(c) consulting people	T	T	
3. PREDICTING	S	S	
4. HYPOTHESIZING	S	S	(DR had to be completed before going to work bench)
5. DESIGNING COLLECTION OF DATA			
(a) defining variables	M	M	
(b) defining experimental steps	M	M, S	
(c) equipment and techniques	M	M	
(d) safety	T	T	
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	
(c) modifying procedures		S	Pb, Ag cells also tested
(d) repeating experiment	S	S	(VTVM used instead of student meters on repeats)
(e) recording data	S	S	
7. OBSERVING AND OBSERVATIONS			(OR had to be completed before end of the period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	
(d) graphical data			
(e) serendipity			
(f) accuracy of data	M	M	
(g) reliability and validity	S	S	
8. ORGANIZING THE DATA			
(a) ordering	M	S	
(b) classifying	M	S	
(c) comparing	M	M	

TABLE 39 (Cont'd)

Lab M4

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating		S	
(b) using statistics		S	
(c) uncertainty of results	M	M	
11. INTERPRETING THE DATA			(Students have to account for the differences in EMF's predicted and observed)
(a) explanation of data	M	M	
(b) generalization or inferences	M	M	
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal			
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	29	33	
INITIATED BY STUDENT	10	18	

TABLE 40

Lab N1 BRONSTED-LOWRY REACTIONS

Key: S= initiated by student, T= guidance provided by teacher and M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	
(c) making assumptions	M	M	
(d) delimiting problem	M	M	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	M	
(b) doing literature research	M	M	
(c) consulting people	T	T	
3. PREDICTING	S	S	
4. HYPOTHESIZING	M	M	
5. DESIGNING COLLECTION OF DATA			(Must complete DR before going to the lab bench)
(a) defining variables	M	M	
(b) defining experimental steps	M	S	
(c) equipment and techniques	M	M, S	
(d) safety	T	T	
(e) method for recording data	M	S	Designs table
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	
(c) modifying procedures		S	(Additional species tested)
(d) repeating experiment		S	
(e) recording data	S	S	Tables not provided
7. OBSERVING AND OBSERVATIONS			(OR must be completed before end of lab period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	
(d) graphical data			
(e) serendipity		S	Unexpected results lead to further discussion
(f) accuracy of data	M	M	
(g) reliability and validity	S	S	
8. ORGANIZING THE DATA			Predictions and observations have to be ordered, and classified
(a) ordering	S	S	
(b) classifying	S	S	
(c) comparing	S	S	

TABLE 40 (Cont'd)

Lab N1

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating			
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			Students have to distinquish between obsevations and interpretations
(a) explanation of data	M	M, S	
(b) generalization or inferences			
(c) assessing validity of predictions	M	M	
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal	M	M	
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP			
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence		T	
(b) test generalizability		T	
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations		S	HCO_3^- and HSO_3^- with Ph$^-$ and Bb$^-$ respectively
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	28	34	
INITIATED BY STUDENT	11	19	

TABLE 41

Lab N2 STANDARDIZATION TITRATION

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	
(c) making assumptions	M	M	
(d) delimiting problem	M	M	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M	S	Lab M3
(b) doing literature research	M	S	ALCHEM and library
(c) consulting people	T	T	
3. PREDICTING			
4. HYPOTHESIZING			
5. DESIGNING COLLECTION OF DATA			(DR had to be completed before going to work bench)
(a) defining variables	M	S	
(b) defining experimental steps	M	S	Designs all steps
(c) equipment and techniques	M	S	
(d) safety	T	T	
(e) method for recording data	M	S	Designs format
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	
(c) modifying procedures		S	
(d) repeating experiment	M	S	
(e) recording data	M	S	
7. OBSERVING AND OBSERVATIONS			(OR had to be comleted before end of lab period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	
(d) graphical data			
(e) serendipity			
(f) accuracy of data	S	S	Students have to obtain
(g) reliability and validity	S	S	less than 10% error
8. ORGANIZING THE DATA			
(a) ordering	M	S	
(b) classifying	M	S	
(c) comparing	S	S	

TABLE 41 (Cont'd)

Lab N2

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			From balanced net equation students have to find $[HCl] = 2 \cdot n(CO_3^{-2})/Vol(HCl)$
(a) calculating	S	S	
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			
(a) explanation of data	M	M	
(b) generalization or inferences	M	M	
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal			
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP	S	S	
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE			
TOTAL NUMBER OF SUBSKILLS	29	30	
INITIATED BY STUDENT	11	22	

TABLE 42

Lab N3 TITRATION - NH_3

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING			
A. PROBLEM			
(a) speculating	M	M	
(b) identifying variables	M	M	
(c) making assumptions	M	M	
(d) delimiting problem	M	M	
2. SEEKING BACKGROUND INFORMATION			
(a) recalling experiences	M, S	S	Lab M3 and Lab N2
(b) doing literature research	M, S	S	
(c) consulting people	T	T	
3. PREDICTING			
4. HYPOTHESIZING			(Must complete the DR before going to the lab bench)
5. DESIGNING COLLECTION OF DATA			
(a) defining variables	M	S	
(b) defining experimental steps	M	S	
(c) equipment and techniques	M	S	
(d) safety	T	T	
(e) method for recording data	M	S	Designs format
6. COLLECTION OF DATA			
(a) setting up apparatus	S	S	
(b) performing experiment	S	S	
(c) modifying procedures	S	S	
(d) repeating experiment	M	S	
(e) recording data	M	S	
7. OBSERVING AND OBSERVATIONS			(OR must be completed before end of lab period)
(a) qualitative data	S	S	
(b) quantitative data	S	S	
(c) gathering specimens	S	S	
(d) graphical data			
(e) serendipity			
(f) accuracy of data	S	S	Percent error had to be less than 8%
(g) reliability and validity	S	S	
8. ORGANIZING THE DATA			
(a) ordering	M	S	
(b) classifying	M	S	
(c) comparing	S	S	

TABLE 42 (Cont'd)

Lab N3

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			From balanced net equation students have to determine $[NH_3] = [HCl](Vol\text{-}HCl)/10$
(a) calculating	M, S	S	
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			Students have to show that pH at the end point is within the pH range of the indicator used
(a) explanation of data	M	M	
(b) generalization or inferences	M	M	
(c) assessing validity of predictions			
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal			
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP	S	S	
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence			
(b) test generalizability			
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables			
(b) unexpected observations			
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE	S	S	
TOTAL NUMBER OF SUBSKILLS	30	30	
INITIATED BY STUDENT	14	22	

TABLE 43

Lab N4 COMMON ION EFFECT

Key: S= initiated by student, T= guidance provided by teacher and
M= guidance provided by laboratory manual

PROCESSES	ALCHEM	REVISED	COMMENTS
1. IDENTIFYING AND FORMULATING	*		*This experiment is not included in ALCHEM 30
A. PROBLEM			
(a) speculating		S	
(b) identifying variables		S	The problem had to be identified
(c) making assumptions		S	
(d) delimiting problem			
2. SEEKING BACKGROUND INFORMATION			An Inventory of Processes in Scientific Inquiry
(a) recalling experiences		S	
(b) doing literature research		S	ALCHEM and library
(c) consulting people		S	
3. PREDICTING		S	
4. HYPOTHESIZING		S	
5. DESIGNING COLLECTION OF DATA			(DR had to be completed before going to work bench)
(a) defining variables		S	
(b) defining experimental steps		S	
(c) equipment and techniques		S	
(d) safety			
(e) method for recording data		S	Designs format
6. COLLECTION OF DATA			
(a) setting up apparatus		S	
(b) performing experiment		S	
(c) modifying procedures		S	
(d) repeating experiment			
(e) recording data		S	
7. OBSERVING AND OBSERVATIONS			(OR had to be completed before end of the period)
(a) qualitative data		S	
(b) quantitative data		S	
(c) gathering specimens		S	
(d) graphical data			
(e) serendipity			
(f) accuracy of data			
(g) reliability and validity			
8. ORGANIZING THE DATA			
(a) ordering			
(b) classifying			
(c) comparing		S	

TABLE 43 (Cont'd)

Lab N4

PROCESSES	ALCHEM	REVISED	COMMENTS
9. REPRESENTING THE DATA GRAPHICALLY			
(a) graphs, diagrams, ...			
(b) interpolating, extrapolating			
10. TREATING THE DATA MATHEMATICALLY			
(a) calculating		T	
(b) using statistics			
(c) uncertainty of results			
11. INTERPRETING THE DATA			Le Chatelier's Principle or equilibrium constant method had to be used
(a) explanation of data		S	
(b) generalization or inferences		S	
(c) assessing validity of predictions		S	
12. FORMULATING OPERATIONAL DEFINITIONS			
(a) verbal		S	
(b) mathematical			
13. EXPRESSING DATA IN THE FORM OF A MATHEMATICAL RELATIONSHIP		T	
14. INCORPORATING THE NEW DISCOVERY INTO THE EXISTING THEORY			
15. SEEKING FURTHER EVIDENCE TO:			
(a) increase confidence		T	
(b) test generalizability		T, S	
16. IDENTIFYING NEW PROBLEMS FOR INVESTIGATIONS BECAUSE OF:			
(a) effect of new variables		T	
(b) unexpected observations		T	
(c) inconsistencies in theory			
17. APPLYING THE DISCOVERED KNOWLEDGE		T	
TOTAL NUMBER OF SUBSKILLS		31	
INITIATED BY STUDENT		25	

APPENDIX B

Revised ALCHEM 30

Laboratory Investigations

CONTENTS

PREFACE

LABORATORY REPORTS

SAFETY AND EFFICIENCY IN THE CHEMISTRY LABORATORY

UNIT L

LAB L1 Molar Heat of a Chemical Change

LAB L2 Molar Heat of Vaporization

LAB L3 Molar Heat of a Phase Change

UNIT M

LAB M1 Introduction to Redox

LAB M2 Spontaneous Reactions

LAB M3 Redox Titration

LAB M4 Electrochemical Cells

UNIT N

LAB N1 Bronsted-Lowry Reactions

LAB N2 Standardization Titration

LAB N3 Titration - NH_3

LAB N4 Common Ion effect

CHEMISTRY 30 - LABORATORY INVESTIGATIONS

PREFACE

In laboratory work the student may be given varying amounts of instruction or guidance by the laboratory manual and by the teacher. In Chemistry 30 you will be doing experiments in which you will have to do more of the planning such as designing experimental steps, tabulating observations, and interpreting data. The first laboratory experiment in each unit will contain considerable direction, but in subsequent experiments you will be given less guidance. Indeed, this year, one of the major objectives of the laboratory work is to learn how to use such scientific process skills as designing experimental steps, tabulating observations and interpreting data. This is not necessarily easy to do, but you will probably never learn these important skills if you are not given the opportunity.

In each experiment you will be given a problem (PURPOSE), and in order to solve the problem you will require background information, some of which will be provided in ALCHEM, some in the classroom, and some in the PRELAB INFORMATION.

The laboratory report, explained in greater detail on the next page, consists of three parts: Design, Observation and Final Reports. The Design Report is due at the beginning of the laboratory period, the Observation Report is due at the end of the period, and the Final Report within two days.

LABORATORY REPORTS

DESIGN REPORTS (DR) (5 marks)

1. The DR should be original and within the limitations given.
2. Experimental steps are to be expressed both quantitatively and qualitatively.
3. Quantitative statements are to be expressed to the correct number of significant figures. These are dictated by the limitations of the equipment.

OBSERVATION REPORT (OR) (5 marks)

1. The OR must show evidence of organization and structure.
2. Data are to be tabulated (matrix, heading, subheadings, etc.)
3. Each trial or experiment is to labelled.
4. Recorded data are to be consistent with the DR.
5. Data are to be expressed to the correct number of significant digits.
6. Changes in experimental procedure different from the design should be included at the end or on the back of the OR.

FINAL REPORT (FR) (10 marks)

This report is an interpretation of your data and an assessment of the extent to which the purpose of the experiment was achieved. Specifically, the report should include the following:

1. Equations for all reactions
2. Answers to all questions in the exercises of the experiment
3. Calculations for each trial including sources and amount of error
4. Only a single determination which should be an average value for all trials
5. Only a single per cent error based on the average determination and the accepted value, whenever possible
6. A brief outline of all formulas (including units for each symbol) and principles underlying the experiment (Theory)

The interpretation should include a discussion of findings: explanation, generalization, validity of assumptions, delimitation, omissions, and general comments about the quality of your work.

Design steps and recorded data need not be included in this report since these are in the DR and OR.

SAFETY AND EFFICIENCY IN THE CHEMISTRY LABORATORY

1. Every student should know where the following are located: (When to use and how to use will be explained in class).

   a) Fire extinquisher (next to main blackboard)
   b) First-aid Kit (above paper towel dispenser)
   c) Safety goggles (last drawer next to NW door)
   d) Eye wash bottle (inside of Chemical Storage Room door)
   e) Rubber bands for long hair (inside of C.S.R. door)
   f) Sodium bicarbonate $NaHCO_3$ for acid burns and spills (outside of C.S.R. door)
   g) Boric acid solution for base burns and spills (outside of C.S.R. door)

2. Check wall charts for the use of bunsen burner, balance, pipet, and correct boiling techniques.

3. Broken glass is to be placed in the metal garbage cans. The plastic containers are to be used for all other insoluble wastes.

4. All students are to wear safety goggles if there is a danger to the eyes.

5. All students will wear protective clothing during every lab session. (Lab coats, jackets, or oversize white shirt)

6. Chemical spills on face or hands should be flushed immediately with plenty of water. (Li, Na, K, etc. are, of course, exceptions)

7. Students in Grades X and XI are not to remove equipment from lab Boxes A or E. Grade XII students are not to remove equipment from Lab Boxes B, C, or D.

8. No solid materials are to be put down the sinks. (e.g. matches, cotton batting, broken glass, etc.)

9. Students are to clean up after each lab. The work area should not be cluttered with test-tubes, racks, beakers, graduate cylinders, etc.

10. Students working next to sinks are responsible for cleaning them after each lab period. Special cleaning materials are available for difficult stains.

11. Lab boxes are to be locked after each lab period.

12. Students are not permitted into the Chemical Storage Room.

13. Asbestos pads and large retort stands are to be left out on the laboratory tables while all other materials should be stored.

14. The chemical balances should not be moved about (otherwise they must be recalibrated), nor should any chemical be placed directly on the pans (always tare). Please return the weights.

LAB L1

MOLAR HEAT OF A CHEMICAL CHANGE

PURPOSE:

To determine the molar heat of a chemical reaction. Specifically, you are to measure experimentally the molar heat of reaction for NaOH in the neutralization reaction with one of the strong acids available (H_2SO_4, HNO_3 or HCl).

PRELAB INFORMATION AND BACKGROUND THEORY:

Before attempting lab L1 laboratory exercise the following prelab information must be covered. (classroom, library, Alchem homework, etc.)

a. laws of thermodynamics, p. L6
b. specific heat (c), p. L7
c. $m \cdot c \cdot \Delta t$ change, p. L8, L9, L16
d. molar heat of a chemical change, pL15, L16
e. use of a calorimeter
f. use and limitations of measuring instruments
    i) graduate cylinder ± 0.1 ml
    ii) thermometer ± 0.1°C
    iii) balance (Rm 11) ± 0.01 g

The Section on Molar Heats of Reaction of page L16 explains how to measure the energy released or absorbed during a chemical change. In this experiment the amount of energy produced by the neutralization is determined by calculating the heat energy change ($m \cdot c \cdot \Delta t$) of the resultant mixture of acid and base. In other words, it is not necessary to put water in the calorimeter at the outset; but, rather, the salt solution produced by the neutralization of the acid and base is the water in the calorimeter (page L16).

The heat of reaction will be measured for the neutralization of 1.0 mol/L acid with 50 ml of 1.0 mol/L NaOH using two nested styrofoam cups as a simple but efficient calorimeter. The heat produced by the neutralization reaction will heat a measured amount of aqueous solution in the calorimeter. Unless directed otherwise by the teacher, the assumption is made that small losses to the calorimeter, air and the thermometer will be ignored. Also assume that the solutions used and produced have a specific heat of $4.19 J/g \cdot {}^{o}C$ and a density of 1.00 g/mL

PRELAB EXERCISES:

a) Write balanced chemical equations for the reactions between the substances you have chosen. Use simplest whole number coefficients.

b) Calculate the volume for each species you intend to use.

MATERIALS:

The following are available: (Other materials are permitted if available and can be safely used.)

Styrofoam cups
$NaOH_{(aq)}$ 1.0 mol/L
$H_2SO_{4(aq)}$ 1.0 mol/L
$HNO_{3(aq)}$ 1.0 mol/L
$HCl_{(aq)}$ 1.0 mol/L
Celsius thermometers

PROCEDURE AND OBSERVATIONS:

Design and perform an experiment which will enable you to measure the amount of heat produced per mole of NaOH during the neutralization of this base with any strong acid listed above.

CALCULATIONS:

1. Calculate the molar heat of reaction for $NaOH_{(aq)}$. Show all work.
2. Calculate the % error. (The accepted value for NaOH for this neutralization reaction is -57kJ/mol.)
3. Determine the molar heat of reaction for water and $H_2SO_{4(aq)}$ in this neutralization reaction.

INTERPRETATION:

See bottom of p.2, Laboratory Reports.

LAB L2

MOLAR HEAT OF VAPORIZATION

PURPOSE: To calculate the molar heat of vaporization of water.

PRELAB INFORMATION:

Heat distilled water in a large test tube until it boils. Do not connect the delivery tube to the calorimeter during the boiling process. Once steam is being generated, connect the tube to the calorimeter with the thermometer in place and continue boiling until the temperature of the calorimeter water increases. At this point carefully remove the tube feeding the calorimeter and record the maximum temperature of the water in the calorimeter, stirring constantly with the thermometer. Other safety precautions will be given on lab day.

MATERIALS:

See page 6 for a diagram of the apparatus.

PROCEDURE:

Design an experiment to measure the molar heat of vaporization of water. Take into account the instructions under "Prelab Information" and the diagram on page 6.

CALCULATIONS:

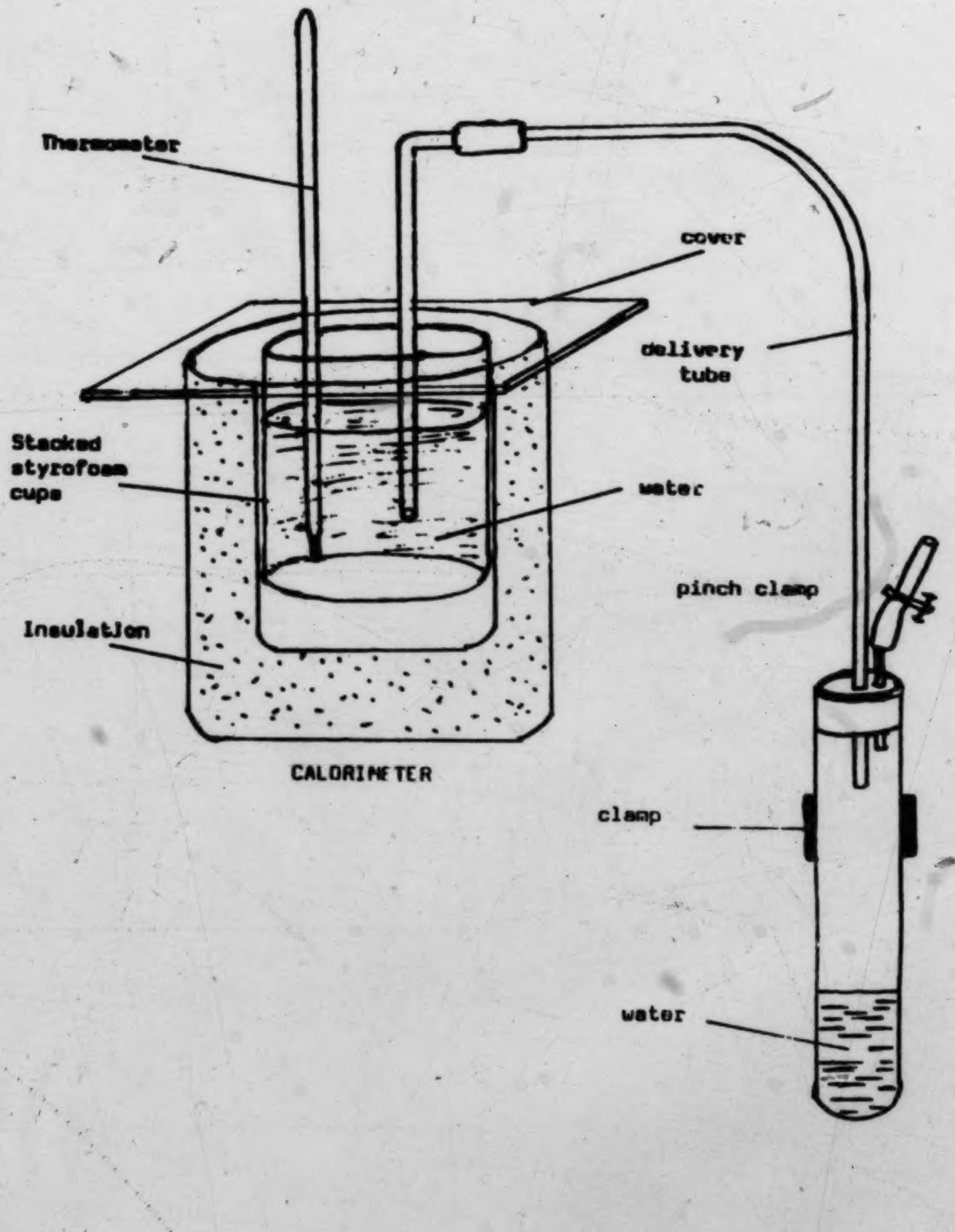
Compute the molar heat of vaporization of water, compare with the value in the Data Sheet and determine the per cent error.

INTERPRETATION:

See bottom of page 2 of Laboratory Reports in this manual.

LAB L2

MOLAR HEAT OF VAPORIZATION APPARATUS


Thermometer
cover
delivery tube
Stacked styrofoam cups
water
pinch clamp
Insulation
CALORIMETER
clamp
water

LAB L3

MOLAR HEAT OF A PHASE CHANGE

PURPOSE:

To determine the molar heat of melting for water.

PRELAB INFORMATION AND BACKGROUND THEORY:

In this lab you are trying to discover an experimental value for the molar heat of melting (fusion) for water.

The molar heat of fusion of ice, which is an example of the molar heat of a phase change, is the amount of heat required to melt one mole of ice without a temperature change. It is not necessary to use exactly one mole of ice to find this change. In this lab one ice cube will do nicely. Of course its mass will have to be determined. Also, the ice cube will melt faster if it is crushed and less heat will be absorbed from the environment.

Calorimeters are used to measure the amount of heat absorbed or lost during an energy change. In this experiment the styrofoam cup is the insulated container. A known mass of water is placed in the cup and its temperature is recorded. The ice will have to be dropped into the cup, so allow sufficient space for the ice. The temperature of the water should be adjusted so that its temperature is a little higher than room temperature, (say, 30° C) Why?

The details of how you are to manage these procedures is left up to you. Be specific and especially quantitative. Just remember anyone reading your directions should be able to duplicate your results. This will require some careful design on your part so that on lab day things will go smoothly. However, while performing the experiment if you realize that your design is not sound, stop and modify it. Make sure you record all changes.

MATERIALS:

You may use any material or apparatus in your laboratory boxes or any materials which are available in the chemical stores (these must be determined beforehand and be approved by the teacher).

PROCEDURE:

State the experimental steps you intend to use. Be specific about data collected, i.e., state mass, temperature, etc.

CALCULATIONS:

Calculate the molar heat of fusion of ice.

INTERPRETATION:

1. State to what extent the purpose was achieved
2. Discuss how you can improve the value you obtained.

LAB M1

ELECTROCHEMISTRY - AN INTRODUCTION TO REDOX

PURPOSE:

1. To determine experimentally whether or not a reaction occurs when certain metals are placed in aqueous solutions containing certain metallic ions.
2. To compare the relative tendencies of metals to react with metallic ions in aqueous solution and conversely to compare the relative tendencies of metallic ions in aqueous solution to react with metals.

PRELAB INFORMATION AND BACKGROUND THEORY:

Chemical reactions which occur on their own, without the input of additional energy, are termed spontaneous. In this lab it is determined experimentally whether certain single replacement reactions are spontaneous or nonspontaneous. In each of the following situations write balanced equations to represent the reaction expected. Use subscripts to indicate the state of matter of each species. All the metal strips are free of oxides and all the solutions are aqueous. See ALCHEM 20 Unit I and Review Unit K for writing net ionic equations.

1. A copper strip is placed in a solution of lead (II) nitrate.
2. A copper strip is placed in a solution of silver nitrate.
3. A zinc strip is placed in a solution of copper (II) nitrate.
4. A zinc strip is placed in a solution of lead (II) nitrate.
5. A zinc strip is placed in a solution of silver nitrate.
6. A lead strip is placed in a solution of copper (II) nitrate.
7. A lead strip is placed in a solution of zinc nitrate.
8. A lead strip is placed in a solution of silver nitrate.
9. A silver strip is placed in a solution of copper (II) nitrate.
10. A silver strip is placed in a solution of zinc nitrate.
11. A silver strip is placed in a solution of lead (II) nitrate.

LAB M1 (Cont'd)

MATERIALS:

Four strips of each of the metals: Cu, Zn, Pb, and Ag.
15 ml of 0.10 mol/L: $Cu(NO_3)_2$, $Zn(NO_3)_2$, $Pb(NO_3)_2$, $AgNO_3$

PROCEDURE:

Design your own experiments to investigate the reaction of the metal strips on the solutions provided. Make sure each metal strip is cleaned to remove any surface coatings. All possible combinations should be tried.

OBSERVATIONS:

Tabulate your observations. Your table should indicate any evidence of a chemical change. Refer to the prelab exercises.

INTERPRETATIONS (QUESTIONS):

1. Go back to the equations in the Prelab Information and indicate which reactions are spontaneous and which are nonspontaneous by writing spont or nonspont on the net ionic equation.
2. What generalization can be made about the reaction between a metal and its own aqueous ion?
3. If the forward reaction is spontaneous will the reverse reaction also be spontaneous? Explain.
4. List the metallic ions in order of their tendency to form metals, from greatest to least. (Place the ion which reacted with the most number of metals at the top of the list and the ion which reacted with the least number of metals at the bottom of the list.)
5. List the metals in order of their tendency to form positive ions, from greatest to least. (Place the metal which reacted with the most number of ions at the top of the list and the metal which reacted with the least number of ions at the bottom of the list.)
6. What generalization would enable you to predict the spontaneity of a reaction? Construct a table from which this generalization can readily be seen.
7. Other conclusions, explanations, generalizations, etc.

LAB M2

ELECTROCHEMISTRY - SPONTANEOUS REACTIONS

PURPOSE:

1. To determine experimentally which combinations of given solutions will react spontaneously.

2. To determine the relative strengths of the oxidizing agents (OA) and reducing agents (RA) determined in No. 1 above and place the agents correctly in a table similar to the Reduction Potential Table in ALCHEM (see Data Sheet, Table 4, side 1).

PRELAB INFORMATION:

This laboratory experiment is similar to Lab M1. You will be given on lab day six chemical species (different from those in Lab M1) and be required to determine experimentally which pairs react spontaneously. You will need to tabulate data in an organized fashion so that the relationships mentioned in the Purpose above can be found. Review Lab M1 and ALCHEM NOTES pp. M5, M6, M8, M9, M10. Note especially step 5, p. M10.

MATERIALS:

Chemical species A, B, C, X, Y, Z, and other necessary materials.

PROCEDURES AND OBSERVATIONS:

1. Color tests to identify and distinguish each of the species in this experiment will be demonstrated on lab day.

2. The Observation Report should indicate evidence for a chemical change in each case.

INTERPRETATIONS:

Give a brief explanation of your findings. Both parts of the Purpose (1 and 2 above) can be answered by placing the agents A, B, C and X, Y, Z in a table similar to the one obtained in Lab M1.

LAB M3

REDOX TITRATION

PURPOSE:

1. To prepare a standard iron (II) solution using the primary standard, iron (II) ammonium sulfate hexahydrate ($FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$).
2. To determine the molar concentration of an aqueous potassium permanganate solution.

PRELAB INFORMATION:

Aqueous solutions of $KMnO_4$ are frequently used in redox titration because the $MnO^-_{4(ag)}$ ion is a strong oxidizing agent in acidic solution. The $MnO^-_{4(ag)}$ ion reacts rapidly and stoichiometrically in acidic solution and undergoes a convenient color change which indicates the end point of the reaction.

However, $KMnO_4$ can not be used as a primary standard because its aqueous solutions become somewhat decomposed right after preparation. The instability of a freshly prepared $MnO^-_{4(ag)}$ solution is caused by organic matter contained in the distilled water. Some of the $MnO^-_{4(ag)}$ ions decompose while oxidizing this organic matter. It is necessary to prepare a $MnO^-_{4(ag)}$ ion solution of approximately the desired strength, let it stand for a day or two, then standardize it against a primary standard reducing agent. In this lab a solution of the primary standard, $FeSO_4 \cdot (NH_4)_2SO_4\ 6H_2O$, will be prepared and used to standardize a previously prepared solution of MnO^-_4.

PRELAB EXERCISE:

1. Calculate the mass of $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ required to make 100 mL of 0.0500 mol/L solution.
2. Write the balanced net ionic equation for the reaction of $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ and $KMnO_4$ in an acidic solution.

MATERIALS:

$FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O_{(s)}$

1 - 100 mL volumetric flask
1 - 250 mL Erlenmeyer flask
1 - 50 mL buret
1 - 10 mL pipet
1 - meniscus finder

1 - medicine dropper

1 - small pipet bulb
1 - stirring rod
1 - 10 mL graduated cylinder
1 - shortstemmed funnel
$KMnO_{4(ag)}$ of unknown concentration

stock solution of 3 mol/L $H_2SO_{4(ag)}$

PROCEDURES AND OBSERVATIONS:

Part A:

1. Use a balance and a piece of paper to obtain the mass of $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O_{(s)}$ determined in the Prelab Exercise.

2. Use a 100 mL beaker to obtain about 40 mL 3 mol/L $H_2SO_{4(aq)}$.

3. Transfer the $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O_{(s)}$ to the beaker containing 40 mL of 3 mol/L $H_2SO_{4(aq)}$. Stir the mixture until all the $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O_{(s)}$ has dissolved. Rinse the stirring rod into the beaker.

4. Use the funnel to transfer the $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ solution from the 100mL beaker to the 100 mL volumetric flask. Rinse the beaker into the volumetric flask.

5. Use the distilled water to dilute the solution to exactly 100mL (Use a meniscus finder and a medicine dropper.) Mix thoroughly by inverting the volumetric flask several times.

6. Obtain about 70 mL of $KMnO_{4(aq)}$ solution of unknown concentration.

7. Clean and rinse the 50 mL buret and funnel with 2 or 3-5 mL portions of the $KMnO_{4(aq)}$ solution. Fill the buret and record the initial buret reading of the permanganate solution to the nearest 0.1 mL. (Note: Use the upper edge of the meniscus since the bottom of the meniscus is obscured.)

8. Rinse a 10 mL pipet with water and then with iron (II) solution from the volumetric flask.

9. Pipet 10.0 mL of the standard iron (II) solution into a clean 250 mL Erlenmeyer flask.

10. Place a piece of white paper under the Erlenmeyer flask so the color of the solution can be seen better.

11. Titrate the sample of iron (II) salt solution with the permanganate solution. Swirl the solution in the Erlenmeyer to ensure complete mixing.

    (When a single drop brings about a faint persisting pink tinge in the liquid, the endpoint has been reached.)

12. Record the final buret reading.

13. Repeat Steps 9-12 two more times.

14. When finished rinse all glassware with tap water.

PART B:

PURPOSE:

To determine the concentration of a hydrogen peroxide solution by using the standardized $KMnO_4$ solution from Part A.

MATERIALS:

1 - 50 mL buret	$KMnO_{4(aq)}$ (Standardized in Part A)
1 - 10 mL pipet	$H_2O_{2(aq)}$ unknown concentration

PROCEDURES AND OBSERVATIONS:

1. Design your own experimental steps to determine the concentration of the H_2O_2 solution. Use techniques similar to Part A.
2. Use 10 mL aliquots of the unknown hydrogen peroxide in an Erlenmeyer flask and titrate with the potassium permanganate solution whose concentration was determined in Part A.
3. Record all observations.

CALCULATIONS: (Part A and Part B)

1. Show calculations for the molar concentration of the $KMnO_4$ solution. (Part A)
2. Show calculations for the molar concentration of the H_2O_2 solution. (Part B)

INTERPRETATIONS AND QUESTIONS:

1. Discuss your findings for Part A and Part B.
2. What is the purpose of adding H_2SO_4 to the Fe^{2+} solution before titrating with $KMnO_{4(aq)}$?
3. Why is H_2SO_4 not added to the $KMnO_4$ solution as a prepared reagent?

LAB M4

ELECTROCHEMICAL CELLS

PURPOSE:

1. To predict the voltage and direction of electron flow of various electrochemical cells.

2. To construct and measure the E M F of various electrochemical cells.

PRELAB INFORMATION:

A number of electrochemical cells will be constructed in the lab. Use the electrochemical cell diagrams on the next three pages to analyze the following cells which will be constructed in the laboratory. The 0.10 mol/L solutions used are $ZnSO_{4(aq)}$, $CdSO_{4(aq)}$, $CuSO_{4(aq)}$ and $K_2Cr_2O_7$.

1. $Zn_{(s)}/Zn^{2+}_{(aq)}//Cr_2O^{2-}_{7(aq)}, H^+_{(aq)},/C_{(s)}$
2. $Cd_{(s)}/Cd^{2+}_{(aq)}//Cr_2O^{2-}_{7(aq)}, H^+_{(aq)},/C_{(s)}$
3. $Cu_{(s)}/Cu^{2+}_{(aq)}//Cr_2O^{2-}_{7(aq)}, H^+_{(aq)},/C_{(s)}$
4. $Zn_{(s)}/Zn^{2+}_{(aq)}//Cu^{2+}_{(aq)}/Cu_{(s)}$
5. $Zn_{(s)}/Zn^{2+}_{(aq)}//Cd^{2+}_{(aq)}/Cd_{(s)}$
6. $Cd_{(s)}/Cd^{2+}_{(aq)}//Cu^{2+}_{(aq)}/Cu_{(aq)}$

Example: The shorthand notation used above is designed to convey the essential information about an electrochemical cell.

$$\underbrace{Zn_{(s)}/Zn^{2+}_{(aq)}//}_{\text{contents of one half-cell}} \quad \underbrace{Cr_2O^{2-}_{7(aq)}, \quad H^+_{(aq)}, \quad / \, C_{(s)}}_{\text{contents of the other half-cell}} \searrow \text{inert electrode}$$

A solidus (/) is used to separate the formulas for chemical species which are in different phases. A comma (,) is used to separate the formulas for chemical species which are in the same phase. A double solidus (//) is used to represent a salt bridge or a porous cup.

LAB M4 (Cont'd)

MATERIALS:

Strips of Cd, Cu, Zn, Ag, Pb

DC voltmeter, VOM or VTVM

$H_2SO_{4(aq)}$ 6.0M

$K_2Cr_2O_{7(aq)}$, (0.13 M);

$CdSO_4$, $CuSO_4$, $AgNO_3$, $Pb(NO_3)_2$,

$ZnSO_4$ (all solutions are 0.10M)

PROCEDURES:

1. Design electrochemical cells using all possible combinations with the available metals and solutions.

2. Determine which electrode should be the anode for each cell.

4. Construct six of the cells which you designed in No. 1 and measure the EMF of each cell.

4. Record all necessary experimental steps. These should be sufficiently complete and clear to enable someone else to duplicate the experiment.

5. For each cell indicate how the voltmeter is to be connected.

6. Unless the VTVM is used (very little current is drawn by this meter), the voltmeter should be connected only long enough to obtain a reading. The solutions used in this way are thereby affected very little and may be used again by you, but do not return the solutions to the reagent bottles.

OBSERVATIONS:

Tabulate data for all electrochemical cells measured. Use the shorthand notation illustrated on page M26, and indicate in your report the anode electrode, the predicted EMF, and the actual observed EMF.

INTERPRETATIONS:

1. Compare predicted EMF's with observed EMF's by calculating the percent error of each cell.

2. Account for the differences.

3. Write balanced net equations for each cell reaction.

LAB N1

BRONSTED - LOWRY REACTIONS

PURPOSE:

To illustrate that the results of an acid-base reaction can be predicted by Bronsted-Lowry Theory.

PRELAB EXERCISES:

For each reaction below predict the products and state how you would detect these products (observation) if the reactions were performed. WRITE NET IONIC EQUATIONS and show by means of the system of arrows whether the forward or reverse reaction is favored as equilibrium is being approached. (See Table 8 on the ALCHEM data sheet.)

1. An ammonium chloride solution is mixed with a sodium hydroxide solution.
2. Aqueous solutions of sodium acetate and hydrochloric acid are mixed.
3. A sodium hydrogen carbonate solution reacts with a sodium hydrogen sulfate solution.
4. A sodium benzoate solution is mixed with a sodium hydrogen sulfate solution. (Hint for observation: See p. N27, ALCHEM)
5. A methyl orange solution, $Mo^-(aq)$, is put into a hydrochloric acid solution.
6. A bromthymol blue solution, $Bb^-(aq)$ is mixed with a sodium hydrogen carbonate solution.
7. A phenolphthalein solution, HPh(aq), is added to NaOH solution.

LAB N1 (Cont'd)

MATERIALS:

1. NH_4Cl, NaOH, $NaCH_3COO$, HCl, $NaHSO_4$, NaC_6H_5COO, and $NaHSO_3$ (All 0.50 mol/L).

2. Indicators: methyl orange (Mo^- form), bronthymal Blue (Bb^- form), and phenolphthalein (HPh form).

PROCEDURES:

1. Design experimental steps and tabulate observations for each reaction given in the Prelab Exercises 1 - 7. The products of the reactions in the Prelab Exercises should provide clues for the predicted observations. Restrict samples of solutions to approximately 5 mL.

2. Add a few drops of each indicator (HPh, Mo^-, and Bb^-) to small samples of HCl, $NaHCO_3$, NaOH, NaC_6H_5COO, $NaHSO_3$, $NaHSO_4$, NH_4Cl, and $NaCH_3COO$.

OBSERVATIONS:

Tabulate all predictions and observations.

INTERPRETATION:

1. Compare predictions with observations for all exercises. List and discuss any conflicting observations and write equations for all reactions.

2. Explain why all indicators do not show a change.

LAB N2

STANDARDIZATION TITRATION

PURPOSE:

To standardize a hydrochloric acid solution with the primary standard Na_2CO_3.

PRELAB INFORMATION:

The reagents most often used as acid and base of standard concentration in laboratories are $HCl_{(aq)}$ AND $NaOH_{(aq)}$. They are both quite stable, inexpensive, and easy to prepare. However, neither in a primary standard (i.e., one from which a solution of known concentration can be prepared to high accuracy). HCl is gaseous in a pure state and commercially sold solutions vary in concentration. NaOH is a deliquescent solid which means it will attract and absorb moisture from the air until it becomes a solution. The absorption of water by NaOH is so rapid that the mass of a sample of pure NaOH cannot be determined accurately.

In this lab the concentration of solutions of $HCl_{(aq)}$ and $NH_{3(aq)}$ will be determined accurately by first titrating a primary standard solution of Na_2CO_3 with the $HCl_{(aq)}$ and then titrating the $NH_{3(aq)}$ with the standardized $HCl_{(aq)}$.

Na_2CO_3 is a primary standard because the solid can be obtained in a very pure form and overnight heating will expel any absorbed water vapor. The pure solid Na_2CO_3 can then be used to prepare a solution of known concentration since the mass of a sample of the solid can be measured very accurately.

MATERIALS:

stock supply of $HCl_{(aq)}$

stock bottles of $Na_2CO_{3(s)}$

50 mL buret

buret clamp

small short-stemmed funnel

100 mL volumetric flask with stopper

10 mL pipet with bulb

methyl orange indicator

LAB N2 (Cont'd)

PROCEDURE:

In the laboratory this year you have been asked, in most of the experiments, to design some of the experimental steps and to tabulate observations. In this laboratory exercise you are being asked to develop a complete experimental design. This design should include all experimental steps, a tabulated format of observations and a comprehensive interpretation. The lab will require careful measurements with the centigram balance and the use of a pipet. Use the indicator methyl orange.

The stock HCl acid has a concentration greater than 0.1M but less than 0.5M. You must, of course, determine the concentration of the HCl acid accurately by using a precise quantity of Na_2CO_3 (primary standard). If you find the mass of approximately 1.5 g (to the nearest 0.01g) of Na_2CO_3 and prepare a 100 mL solution of Na_2CO_3 (using a volumetric flask) you will have enough of the standard for several titrations. These directions are only general guide lines. You will need to be more specific in outlining experimental steps, and this will require some careful planning on your part.

OBSERVATIONS AND INTERPRETATIONS:

Tabulate the data from all titrations and determine the concentration of the NCl as accurately as possible. This concentration will be needed in Lab N3 to determine the concentration of ammonia. Show all calculations.

LAB N3

TITRATION - NH_3

PURPOSE:

To use the standardized solution of HCl from LAB M2 to determine the concentration of ammonia (NH_3).

MATERIALS:

stock bottles of $HCl_{(aq)}$

stock bottles of $NH_{3(aq)}$

50 mL buret
buret brush
liquid soap
buret stand
buret clamp
small short-stemmed funnel
10 mL pipet with bulb
bromthymol blue indicator
250 mL Erlenmeyer flask

PROCEDURE:

Use the $HCl_{(aq)}$ from lab N2 to titrate with 10 mL aliquots of NH_3. The bromthymol blue indicator should be added to the ammonia aliquot in the titration flask (Erlenmeyer) and titrated with HCl until a permanent green color is reached. It is very easy to overshoot the green color. Perhaps you should be prepared with an alternate plan.

OBSERVATIONS:

Tabulate all titrations.

INTERPRETATION:

1. Determine the concentration of the ammonia.
2. Answer all questions on page N52 and discuss your findings.
3. Calculate the pH of the solution at the equivalence point and show that it is within the pH range of the indicator used.

LAB N4

COMMON ION EFFECT

PURPOSE:

To determine what will happen, if to a saturated solution of $NaCl_{(aq)}$ a few drops of concentrated (12 M) $HCL_{(aq)}$ are added.

PRELAB INFORMATION:

In the laboratory this year you have been engaged in processes of scientific inquiry (See the handout An Inventory of Processes in Scientific Inquiry by M. A. May et al).

For this last laboratory experiment you are being asked to identify and exhibit most of the process skills in the inventory. Here are steps you should take into account. There may be others which you may want to add.

PROCESS SKILLS:

1. Speculate about the phenomenon and identify a problem (variables, assumptions, etc.)
2. Seek background information (notes, ALCHEM, etc.)
3. Predict.
4. Hypothesize.
5. Design experimental steps (state equipment, sequence steps)
6. Indicate safety precautions.
7. Go to the lab bench and perform the experiment.
8. Record all observations.
9. Identify failures, unexpected results, repeats, revisions, etc.
10. Process data.
11. Interpret data.
12. Interpret data by assessing the validity of initial assumptions, predictions, and hypotheses.
13. Express the above interpretation of data verbally or mathematically.
14. State what further evidence is needed to substantiate your findings or model.
15. State any applications for this knowledge.

REPORTS:

Your DR should refer to No. 1, 2, 3, 4, 5, and 6; the OR should refer to No. 7, 8, and 9; and the FR should refer to No. 10 to 15.

APPENDIX C

AN INVENTORY OF PROCESS IN SCIENTIFIC INQUIRY

AN INVENTORY OF PROCESSES IN SCIENTIFIC INQUIRY

By M. A. Nay, et al.

I. INITIATION

1. Identifying and formulating a problem
    - (a) speculating about a phenomenon
    - (b) identifying variables
    - (c) noting and making assumptions
    - (d) delimiting the problem
2. Seeking background information
    - (a) recalling relevant knowledge and experiences
    - (b) doing literature research
    - (c) consulting people
3. Predicting
4. Hypothesizing
5. Designing collection of data through field work and/or experimentation
    - (a) defining the independent, dependent and controlled variables
    - (b) defining the procedure and sequencing the steps
    - (c) identifying needed equipment, materials and techniques
    - (d) indicating safety precautions
    - (e) devising the method for recording data

II. COLLECTION OF DATA

6. Procedure
    - (a) collecting, constructing, and setting up the apparatus or equipment
    - (b) doing field work and/or performing the experiment
    - (c) identifying the limitations of the design (as a result of failures, blind alleys, etc.) and modifying the procedure (often by trial-and-error)
    - (d) repeating the experiment (for reproducibility, to overcome limitations of initial design, and more)
    - (e) recording data (describing, tabulating, diagramming, photographing, and so on)

7. Observing and observations
    - (a) obtaining qualitative data (using senses)
    - (b) obtaining semi-quantitative and quantitative data (measuring, reading scales, calibrating, counting objects or events, estimating, approximating)
    - (c) gathering specimens
    - (d) obtaining graphical data (charts, photographs, films, etc.)
    - (e) noting unexpected or accidental occurrences (serendipity)
    - (f) noting the precision and accuracy of data
    - (g) judging the reliability and validity of data

III. PROCESSING DATA

8. Organizing the data
    - (a) ordering to identify regularities
    - (b) classifying
    - (c) comparing

9. Representing the data graphically
    - (a) drawing graphs, charts, maps, diagrams
    - (b) interpolating, extrapolating, etc.

10. Treating the data mathematically
    - (a) computing (calculating)
    - (b) using statistics
    - (c) determining the uncertainty in the results

IV. CONCEPTUALIZATION OF DATA

11. Interpreting the data
    - (a) suggesting an explanation for a set of data
    - (b) deriving an inference or generalization from a set of data
    - (c) assessing validity of initial assumptions, predictions, and hypotheses

12. Formulating operational definitions
    - (a) verbal
    - (b) mathematical

13. Expressing data in the form of a mathematical relationship

14. Incorporating the new discovery into the existing theory (developing a "mental model")

V. OPEN-ENDEDNESS

15. Seeking further evidence to

    (a) increase the level of confidence in the explanation or generalization
    (b) test the range of applicability of the explanation or generalization

16. Identifying new problems for investigation because of

    (a) the need to study the effect of a new variable
    (b) anomalous or unexpected observations
    (c) incompleteness ("gaps") and inconsistencies in the theory

17. Applying the discovered knowledge

APPENDIX D

CHARACTERIZATION OF AN INQUIRY LESSON

CHARACTERIZATION OF AN INQUIRY LESSON

Teaching Modes	Nature of the Structuring and Guidance*	Level of Inquiry
Deductive, "cook-book" lesson mainly for purposes of illustration & verification Inductive lesson the main purpose being "discovery" of the generalization Problem-solving lesson Problem identification & research	1. Directions relative to initiation of an investigation by a student (identifying the problem to be investigated, seeking background information, predicting, hypothesizing, designing, data-collection procedures, etc.) 2. Direction & guidance during the data-collecting activities (assemblage & use of apparatus, what action or changes to look for, measurements & readings to be taken, specimens to be collected, precision noted, etc.) 3. Directions for processing data (graphing, applying mathematics, classifying etc.) 4. Directions for conceptualization of data (interpreting data, "discovering" generalizations, etc.) 5. Suggestions for further proof, new investigations, applications, etc. (open-endedness)	(1) Level of inquiry learning and teaching increases. (2) Structuring of the learning and guidance by the teacher decreases. (3) Independence or self-direction in learning inxreases. (4) Level of creativity (original work) increases.

* The above five clusters of directions are based on "An Inventory of Processes in Scientific Inquiry" by Nay et al (4).

APPENDIX E

AN INVENTORY OF AFFECTIVE ATTRIBUTES OF SCIENTISTS

AN INVENTORY OF AFFECTIVE ATTRIBUTES OF SCIENTISTS

By R. Crocker and M. A. Nay

1. INTERESTS

(The motivation for a person to become a scientist and continue to be one.)

1.1 Understanding natural phenomena
  1.11 Curiosity
  1.12 Fascination
  1.13 Excitement
  1.14 Enthusiasm

1.2 Contributing to knowledge and human welfare
  1.21 Altruism
  1.22 Ambition
  1.23 Pride
  1.24 Satisfaction

2. OPERATIONAL ADJUSTMENTS

(Primary behaviors which underlie competence and success in science, and performance at recognized standards.)

2.1 Dedication or commitment
  2.11 Perseverance (persistence)
  2.12 Patience
  2.13 Self-discipline
  2.14 Selflessness
  2.15 Responsibility
  2.16 Dependability

2.2 Experimental requirements
  2.21 Systematism (methodicalness)
  2.22 Thoroughness
  2.23 Precision
  2.24 Sensitivity
  2.25 Alertness for the unexpected

2.3 Initiative and resourcefulness
  2.31 Pragmatism (common-sense)
  2.32 Courage (daring, venturesomeness)
  2.33 Self-direction (independence)
  2.34 Self-reliance
  2.35 Confidence
  2.36 Flexibility
  2.37 Aggressiveness

2.4 Relations with peers
  2.41 Cooperation
  2.42 Compromise
  2.43 Modesty (humility)
  2.44 Tolerance

3. ATTITUDES OR INTELLECTUAL ADJUSTMENTS

(Intellectual behaviors which are foundational to the scientist's contribution to or acceptance of new scientific knowledge.)

3.1 Scientific integrity
- 3.11 Objectivity
- 3.12 Open-mindedness
- 3.13 Honesty
- 3.14 Suspended judgment (restraint)
- 3.15 Respect for evidence (reliance on fact)
- 3.16 Willingness to change opinions
- 3.17 Idea sharing

3.2 Critical requirements
- 3.21 Critical mindedness
- 3.22 Skepticism
- 3.23 Questioning attitude
- 3.24 Disciplined thinking
- 3.25 Anti-authoritarianism
- 3.26 Self-criticism

4. APPRECIATIONS

(Relative to the foundations, interactions, and dynamics of science.)

4.1 The history of science
- 4.11 The evolution of scientific knowledge
- 4.12 Contributions made by individual scientists
- 4.13 The exponential growth of science

4.2 Science and Society
- 4.21 The social basis of the development of modern science
- 4.22 The contribution made by science to social progress and melioration
- 4.23 The relationship between science and technology
- 4.24 The interaction of the "two cultures"

4.3 The nature of science
- 4.31 The process of scientific inquiry
- 4.32 The tentative and revisionary character of scientific knowledge
- 4.33 The strengths and limitations of science
- 4.34 The value of one's own contribution and the debt owing other scientists
- 4.35 The communality of scientific ideas
- 4.36 The esthetics and parsimony in scientific theory
- 4.37 The power of individual and cooperative effort
- 4.38 The power of logical reasoning (rationality)
- 4.39 The causal, relativistic, and probabilistic nature of phenomena

5. VALUES AND/OR BELIEFS

(In the realm of philosophy, ethics, politics, etc.)

5.1 Philosophical
- 5.11 The universe is "real"
- 5.12 The universe is comprehensible (knowable) through observation and rational thought
- 5.13 The universe is not capricious

5.2 Ethical
- 5.21 Science is amoral but scientists have the responsibility to interpret the consequences of their work
- 5/22 Humanism is the highest idea

5.3 Social
- 5.31 Science must serve the needs of society
- 5.32 Science flourishes best in a free and democratic society

From an article in Science Education, 54:59-67 (1970)

APPENDIX F

PROCESSES OF SCIENCE TEST

(POST)

Pages 246 - 253 inclusive have been removed due to copyright restriction. Included in this section were the Processes of Science Test and associated answer key. The test and answer key are available from the The Psychological Corporation, 304 East 45th Street, New York, N.Y. 10017. The test is described in detail on pages 70 - 71 of this thesis.

APPENDIX G

TEST ON SCIENTIFIC ATTITUDE

(TOSA)

KEY FOR "TEST ON SCIENTIFIC ATTITUDE"

by G. Andruski, M. J. Kozlow and M. A. Nay
University of Alberta

CODE: for attributes:

CM - critical mindedness (questioning attitude)
SJ - suspended judgment
RE - respect for evidence
H - honesty
O - objectivity (and open-mindedness)
WCO- willing to change opinions

CODE: for subtests:

C - cognition
I - intent

ITEM NUMBER	BEST ANSWER	ATTITUDES BEING TESTED	COGNITION OR INTENT	ITEM NUMBER	BEST ANSWER	ATTITUDE BEING	COGNITION OR INTENT
1	A	CM, RE	I	21	B	CM, WCO	C
2	D	SJ, RE	C	22	D	SJ, WCO	C
3	B	O	C	23	A	SJ, RE	C
4	A	O	C	24	C	O	I
5	A	SJ, WCO	C	25	B	CM, RE	I
6	D	SJ	C	26	A	O, WCO	I
7	D	SJ, WCO	C	27	D	SJ	C
8	A	SJ, RE	I	28	B	SJ, O	I
9	C	CM, RE	I	29	B	CM, SJ	I
10	B	SJ	C	30	C	SJ, RE	I
11	B	CM, H	I	31	C	SJ, RE	I
12	A	SJ, RE, O	C	32	B	SJ, O	I
13	C	CM	I	33	D	O, WCO	I
14	D	H	I	34	A	SJ, RE	I
15	B	O	C	35	D	WCO	C
16	C	CM, RE	C	36	B	H	C
17	D	RE, WCO	C	37	C	CM, RE	I
18	D	CM, O	I	38	A	RE, O	I
19	A	H	I	39	D	WCO	C
20	C	RE	C	40	C	H	C

TEST ON SCIENTIFIC ATTITUDE

G. Andruski
M.J. Kozlow
M.A. Nay

Directions:

1. Each question or incomplete statement is followed by four possible answers. Read each question and decide which ONE of the four alternative answers you think is best. Mark your answers on the separate answer sheet. Make certain that the number on the answer sheet corresponds to the number of the question that you are answering.
2. Do not write in this test booklet.
3. Read each question carefully but do not spend too much time on any one question. Answer all questions.
4. Mark only ONE answer for each question.

Example:

200. A person who dedicates his life to the study of chemistry is a

A. biologist C. chemist

B. physicist D. zoologist

Answer Sheet

200. A1 B2 C3 D4
= = ▬ =

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1. Suppose you live near a large industrial plant. You find that the rose bushes in your yard die in a short while after they are planted, but your lawn remains in perfect condition. You suspect that the fumes from the industrial plant are the cause of the death of the roses. Which one of the following would be the most reasonable course of action for you to take?

   A. Study the effect of the fumes on healthy rose bushes.
   B. Stop growing rose bushes.
   C. Start legal action against the plant for pollution control.
   D. Move away from the plant.

Questions 2 and 3 refer to the following paragraph.

The scientist, Schleiden, published a report in 1838 on the origin of plant cells. He made several observations on the reproductive cells of some plants which he explained as follows:

> It is an absolute law that every cell takes its origin as a very small bladder and grows only slowly to its defined size. The process of cell formation which I have just described . . . is that process which I was able to follow in most of the plants which I have studied. Yet many modifications of this development can be observed . . . Nevertheless, the general law cannot be questioned . . .

2. Which one of the following is generally true about scientists but was NOT demonstrated by Schleiden in the above situation?

   A. Scientists may ignore observations which do not quite fit into their theories.
   B. Scientists are usually careful to report exactly what they observe.
   C. Scientists collect large amounts of data in order to develop a law of nature.
   D. Scientists try to avoid making general statements based on limited data.

3. Some aspects of Schleiden's theory were later shown to be not accurate. The most probable reason for this is that he

   A. did not have modern instruments to use in his investigations.
   B. did not make his theory explain all of his observations.
   C. based his cell theory on too few observations.
   D. felt that his theory could not be questioned.

4. Quite often it is possible to give several different explanations for a particular set of observations. Which one of the following would NOT be generally true about such explanations?

   A. Only one of these explanations could be the true scientific one.
   B. The explanation which greatly stimulates further research is likely to be the one which most scientists will accept.
   C. The explanation which is the most widely used is likely to be the accepted one.
   D. All these explanations would be acceptable if they explain the observations adequately.

5. When Einstein published his theory of relativity, another famous scientist was reported to have said, "Dr. Einstein's new theory has shattered many of my scientific beliefs to smithereens!" This statement indicates that the scientist

   A. recognized that scientific knowledge can change.
   B. held some wrong scientific beliefs without knowing it.
   C. did not believe in the old theory very strongly.
   D. did not have sufficient evidence to support his original beliefs.

6. A theory in science is generally accepted when it explains all of the observed properties of the substances involved. However, it is possible that undiscovered properties exist that cannot be explained by the theory. Which one of the following is the BEST approach to this situation?

   A. When exceptions are discovered, scientists should abandon the theory and devise a new one.
   B. Scientists should provide several theories to explain a given set of observations so that if exceptions to one theory are found, they will have others to rely on.
   C. Scientists should not accept a theory until they are certain that exceptions to it do not exist.
   D. The limits under which the theory applies should be carefully stated and the theory should be used within these limits.

7. Scientists recognize that a scientific theory

   A. should not be changed when it is based on a large amount of data.
   B. may have to be changed to keep up with a rapidly changing world.
   C. should not be changed when it explains what happens in nature.
   D. may have to be changed to explain new observations.

8. A boy goes skating on a pond and breaks through the ice. He is rescued and given a drink of hot chocolate by someone who is sneezing and coughing. A few days later the boy also has a cold. Which one of the following best describes the reason for the boy's cold?

   A. The reason why he got a cold is not yet determinable.
   B. He got the cold from the person who rescued him.
   C. He probably had a cold coming before he went skating.
   D. His cold is due to falling in the cold water and getting wet.

9. Scientists have questioned many religious beliefs. Which one of the following best expresses the way you feel concerning this matter?

   A. When scientific theories question religious beliefs, it is better to keep the religious beliefs.
   B. I have two separate thought compartments, one for my religious beliefs and one for scientific knowledge.
   C. I question those religious beliefs upon which science has cast doubt.
   D. I keep my religious beliefs until scientists prove them wrong.

10. A science magazine reports that a scientist produced a type of water that boils at 540°C at sea level. Another scientist reading this report would probably

   A. believe the report if it was written by a highly respected scientist.
   B. neither believe or disbelieve the report until other scientists study this problem.
   C. neither believe or disbelieve the report until it is discussed with friends and other scientists.
   D. disbelieve the report because he would know that water boils at 100°C at sea level.

11. Recently a chemical company was accused of deliberately making false claims about the safety of some of its insecticides. On the basis of these claims the government permitted their use in the human environment. Now there is evidence that these insecticides have caused many people to suffer. Which of the following is the best way to handle this kind of situation?

   A. The chemical laboratory should be barred from developing new insecticides.
   B. The government should check more closely on the safety claims of such potentially dangerous chemicals.
   C. The false claims should be ignored until sufficient evidence is obtained that these insecticides harm humans.
   D. The false claims should be ignored since there is nothing to replace these useful chemicals.

12. A scientist was studying an ore from the moon in an attempt to obtain a new metal from it. He made several tests but did not find evidence of a new metal. However, he did identify a peculiar gas which he obtained during one of the tests. He probably would have

    A. reported that the ore did not contain a new metal but did contain a peculiar gas.
    B. reported only that portion of his investigation related to the gas.
    C. not made any report because he did not use the correct technique to find evidence of a metal.
    D. not made any report until he was able to get another scientist to confirm his identification of the gas.

13. When you are evaluating the correctness of ideas in science textbooks, which one of the following is the most important consideration?

    A. How recently the book was published.
    B. Whether or not the author is a scientist.
    C. How widely the ideas in the book are currently accepted by scientists.
    D. The extent to which the ideas have been simplified.

14. Suppose you had worked several days on a chemistry experiment. You then accidentally added some sodium nitrate solution when you should have added silver nitrate. Which one of the following courses of action should you take?

    A. Add some silver nitrate solution and continue with the experiment.
    B. Continue with the experiment but if it doesn't turn out the way it should, start over again.
    C. Continue the experiment to see if the mistake makes any difference.
    D. Start over again as soon as you realize your mistake.

15. If a scientist had to choose between two theories, he would probably support the theory which

    A. most other scientists feel is more likely to be correct.
    B. explains the available observations more satisfactorily.
    C. is based on a larger number of observations.
    D. has more practical value.

Questions 16 and 17 refer to the following paragraph:

Galileo gathered much evidence on stars, motion of objects, etc. which gave rise to ideas about the universe which were contrary to those held by some of the philosophers of his time. These philosophers forced Galileo to say that he was wrong and tried to stop him from practicing science.

16. Which one of the following best applies to this situation?

    A. Galileo should have collected more evidence before disagreeing with the philosophers.
    B. Galileo's ideas became wrong when he was forced to say that they were.
    C. Galileo was justified in questioning the beliefs of the philosophers.
    D. Galileo should have avoided those investigations which led to disagreement with the philosophers.

17. In their treatment of Galileo, the philosophers

    A. showed that they did not have a proper respect for evidence.
    B. seemed to think that they knew all that there was to know about the universe.
    C. were not willing to change their ideas in the face of new evidence.
    D. showed all of the above characteristics.

18. "People born when certain stars are becoming more prominent show the influence of these stars in their personalities." People who believe this statement

    A. probably have a special ability to understand such influence.
    B. are more imaginative than most people.
    C. are more open-minded than most people.
    D. do not take scientific evidence into account.

19. Suppose you did a chemistry experiment, but the results were not what you expected. Which one of the following would you do?

    A. Report the results that you obtained even though they were not what you expected.
    B. Report the results obtained by a classmate which were the expected results.
    C. Report the results which were predicted in the chemistry text.
    D. Report no results and tell the teacher that the experiment failed.

20. Quite often two groups of scientists will support two opposing theories on some aspect of nature. Which one of the following would be the MOST important point to consider in settling such a controversy?

    A. Both theories give satisfactory explanations for the observations, but one theory has more practical applications.
    B. One group of scientists have had more success in publishing their theory.
    C. Different conclusions are reached when the two theories are applied to certain problems.
    D. One group contains several scientists who have won the Nobel Prize for science.

Questions 21 and 22 refer to the following paragraph.

Priestly and Lavoisier, both of whom lived 200 years ago, are often referred to as the "fathers of modern chemistry". Both of them did many experiments on burning and believed in the phlogiston theory of combustion (all materials give off a substance called "phlogiston" when they burn). However, later Lavoisier became dissatisfied with the phlogiston theory and developed our modern theory of combustion in which he said that when a substance burns it combines with oxygen. Priestley never accepted Lavoisier's theory.

21. Which one of the following is generally true about scientists, but was NOT demonstrated by Priestley in the above situation?

    A. Scientists believe very strongly in their theories.
    B. Scientists accept new theories when they are consistent with experimental data.
    C. Scientists do not accept new theories when they are first published.
    D Scientists demand an excessive amount of experimental evidence before changing their belief in a theory.

22. Which one of the following can be inferred from the above paragraph as NOT true about Lavoisier?

    A. He developed a new theory to explain the evidence on burning.
    B. He recognized that theories are likely to change.
    C. He was prepared to consider ideas presented by others.
    D. He believed that his theory of combustion would never change.

23. Drs. Brown, Jones, and Smith are medical researchers. Each one independently investigated the cancer-producing effect on rats of compounds found in tar. Dr. Brown reported that there was no effect. Some time later, both Drs. Jones and Smith reported that these compounds were highly cancer-producing. Which one of the following was probably the MOST important reason for Dr. Brown's conclusion?

    A. He did not do a sufficient number of controlled experiments.
    B. He did not consider all the evidence.
    C. He was in a hurry to report his results first.
    D. He did not analyze his data properly.

24. Below are a number of points of view regarding the teaching of the theory of evolution in a biology class. In your opinion, this theory should be

    A. omitted from the biology course.
    B. presented to the class, but its controversial aspects should not be discussed.
    C. discussed thoroughly in a democratic manner in class with all students present.
    D. discussed openly in class, but those students who do not want to listen should be permitted to leave.

25. Imagine you are living in a small town on the banks of a river not far from a large industrial city. Your town has just experienced a severe flood for the first time in its recorded history. Some people are saying that it was caused by increased rainfall due to the smog from the nearby industry. Which one of the following best expresses your evaluation of this claim?

    A. This is a popular opinion for which there is no proof.
    B. This is a conclusion for which more evidence is needed.
    C. This is a valid conclusion based on sufficient evidence.
    D. This is a popular opinion based on people's prejudice against smog.

26. In an experiment, students blew through limewater with a straw and noted that it turned milky. From this result most of the students concluded that their bodies gave off carbon dioxide. However, one girl wrote in her notebook that since there is carbon dioxide in the air we breathe, the experiment proved nothing. Which one of the following best describes your evaluation of this situation?

    A. Both sides were partly justified in their conclusions.
    B. The girl was justified in doubting the proof for the body giving off carbon dioxide.
    C. Neither side had sufficient evidence for their conclusion.
    D. The students were justified in concluding that the body gives off carbon dioxide.

27. For more than 100 years chemistry textbooks have presented Arrhenius's theory of ionization to explain the properties of acids, bases and salts. However, at the time Arrhenius first proposed this theory, very few scientists were willing to accept it. Which one of the following is the MOST important reason why the theory was not widely accepted when it was first proposed?

   A. The scientists who would not accept this theory were less willing to be criticized.
   B. The scientists who would not accept this theory were not as imaginative as Arrhenius.
   C. Arrhenius did not have enough evidence to support his theory.
   D. Arrhenius, in his theory, gave a different interpretation to the available data on acids, bases and salts.

28. Nuclear plants are becoming of increasing importance as a source of electricity in industrialized countries. However, dangerous radioactive wastes are produced which must be disposed of safely. Recently, a proposal was made to bury them deep in stable Pre-Cambrian rocks where they must lie undisturbed for hundreds of thousands of years. Which of the following reactions is the most reasonable one for you to take on this issue?

   A. The proposal is sheer madness because this increases the risk of radioactive pollution.
   B. The proposal should be shelved until studies are done on the success of long-term burial of radioactive wastes.
   C. Risks should be taken because the electricity from nuclear plants is badly needed.
   D. The industrialized countries should use less electricity so that nuclear plants would not be necessary.

29. "Light travels as a stream of particles."
   "Light travels as a wave."

   If you came across these two statements in two different science books, which of the following would you do?

   A. Ask your teacher to tell you which statement to accept.
   B. Check other science books for statements on this topic.
   C. Assume that scientists are not certain as to how light travels.
   D. Accept the statement in the newer book.

30. During a discussion of current events in a science class a student reports that much of the research on paranormal power (eg. mental telepathy, clairvoyance, and fortune telling) gives false results. The main reason for these false results is the difficulty in devising proper research methods to study paranormal power. Students who believe in paranormal power upon hearing this report, should react in which one of the following ways?

    A. Continue to believe because eventually new research may show that some people do have paranormal power.
    B. Stop believing in paranormal power until acceptable scientific evidence is obtained to support it.
    C. Read the evidence for and against paranormal power so as to be able to decide whether to continue believing it.
    D. Continue to believe because one knows from one's own experiences that some people have paranormal power.

31. Suppose that you and a friend both did the same experiment to determine whether or not sunlight is required for plants to produce starch. Both of you tested a leaf from a plant that had been left in the dark for two days. Then you both tested a leaf from a plant that had been left in the sunlight. Your friend found starch in both leaves. You found starch only in the leaf from the plant that had been left in the sunlight. Which one of the following would be the most reasonable thing for you to do?

    A. Accept your own result because text books say that plants in the dark should not produce starch.
    B. Accept the result obtained by the one who knows more about the experiment.
    C. Have both of you repeat the experiment.
    D. Ask your teacher to decide which result should be accepted.

32. Consider the following data concerning fluoridation of the public water supply:

    Fluorides help prevent cavities in children's teeth.

    Small amounts of fluorides appear to have no long-term harmful effects on humans.

    The easiest and cheapest way to administer flourides to children is through the public water supply.

    It is safe to put acceptable amounts of fluorides in milk for children.

    Which one of the following best describes your point of view after considering the above information?

    A. You would be against putting fluorides into the public water supply.
    B. You would be uncertain as to which side to support.
    C. You would be in favor of putting fluorides into the public water supply.
    D. You would lose interest in the problem because the evidence is too indefinite.

33. "Cloning" is one kind of experimentation with genes (carriers of heredity) in which identical copies of an organism are produced. This result of cloning has led to claims that it is possible to produce many copies of a human being. Which one of the following reactions do you favor?

    A. Biologists have no business aspiring to "play God."
    B. The possible bad results of duplicating human beings are scary.
    C. Society should protect the sanctity of life by forbidding the cloning of humans.
    D. Cloning of humans should continue because it may help in our understanding of the process of life.

34. Some medical researchers say that marijuana is more harmful to humans than alcohol, while others say that it is not. In the light of this information, which of the following would you be inclined to do?

    A. Put off any decision about smoking marijuana until more definite knowledge is obtained about its effects.
    B. Ignore the evidence that marijuana might be harmful and smoke it if you wanted to.
    C. Smoke marijuana because it is probably no more harmful than alcohol.
    D. Not smoke marijuana because it is harmful.

35. When observations are made that do not fit an accepted scientific theory, scientists usually

    A. try to adjust the observations so that they fit into the theory.
    B. keep the theory as it is since the new observations cannot be used to improve it.
    C. discard the theory and develop a new one to explain these observations.
    D. try to change the theory so that these observations can be explained.

36. It has been stated that secrecy in research is necessary, one reason being that stealing of ideas occurs in science. Which one of the following is the LEAST important reaction to this situation?

    A. Stealing of research ideas is desirable because it informs the wronged scientist that his research is important.
    B. Stealing of research ideas is bad because it may prevent a scientist from getting proper recognition for his ideas.
    C. A certain amount of stealing of research ideas is tolerable since it tends "to keep scientists on their toes."
    D. Such stealing is harmful because it may prevent scientists from sharing ideas, hence slowing down scientific progress.

37. If you come across a scientific idea which goes against your common sense, which one of the following would you be inclined to do?

A. Disregard the scientific idea because it is better to rely on common sense.
B. Disregard common sense because it is not as reliable as scientific study.
C. Do an experiment to determine whether common sense or the scientific idea is more acceptable.
D. Try to produce a compromise between the scientific idea and common sense.

38. "Many people have cycles of mental disturbances which correspond to the phases of the moon." Which one of the following best represents your reaction to this statement?

A. One should be willing to consider the possibility that there may be some truth to this statement.
B. Scientists could never prove or disprove this idea.
C. This statement is true because people have believed in it for a long time.
D. There is insufficient evidence to make such a claim.

39. A scientist shows that he is open-minded when he

A. discusses his ideas with other scientists.
B. asks other scientists to provide experimental evidence to support their ideas.
C. agrees with ideas presented by other scientists.
D. evaluates ideas which do not agree with his theories.

40. Because a scientist is human, he can never be totally objective (without bias) when doing and reporting his research. Yet when he does report his research findings, other scientists usually treat them as accurate and honest. Which of the following statements best explains this apparently contradictory situation?

A. From the report, scientists are able to tell whether there was any cheating.
B. A scientist's strong scientific interests and biases do not have any effect on his findings.
C. Scientists trust such reports because they know that the research can be repeated by other scientists working in the same field.
D. Biased research findings are often very useful in science.

APPENDIX H

LABORATORY QUESTIONNAIRES

LABORATORY QUESTIONNAIRE

One of the purposes of this questionnaire is to provide descriptions of what happens in the classroom. You are asked to state concerns, priorities, interactions (with teacher and other students) and even your personal feelings about your participation in the Chemistry 30 laboratory program. Please indicate what you believe rather than what you think you should believe, or what you think your teacher thinks you should believe.

EXAMPLE: I like to watch NHL hockey broadcasts on TV.

A	B	C	D	E
____	____	____	____	____
strongly agree	agree	neutral	disagree	strongly disagree

If you score the A response, this would indicate that you are very interested in hockey and watch it most of the time. If you score the B response, this would indicate that you watch the TV hockey broadcasts frequently but on some nights you would watch competing programs. If you score the C response, this would indicate that you neither agree nor disagree with the statements. If you score the D response, this would indicate that you watch other programs or do something else more often than watch hockey. If you score the E response, this would indicate that you do not watch hockey at all. In fact you have no interest in the hockey programs.

Space has been provided for your comments. Your responses and comments will be used to evaluate this year's laboratory program and to give an in-depth description of the laboratory setting.

LAB L1

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. In spite of the Prelab Instructions (see page L3), I was not sure what was meant by the molar heat of a chemical change.

____ 2. After performing the experiment and completing the laboratory reports, I was still unsure of what was meant by the molar heat of a chemical change.

____ 3. I am not sure of what is meant by the specific heat of a substance.

____ 4. I am not sure why it was assumed that all solutions (acid and base) have a density of 1.00 g/mL.

____ 5. I felt the instructions given in the laboratory manual on pages L3 and L4 were sufficiently clear.

____ 6. I had difficulty with the Design Report.

____ 7. I did not realize that more than one trial was necessary to obtain significant data (reproducibility).

____ 8. I had difficulty in organizing and recording my data for the Observation Report.

____ 9. I believe more guidance should have been provided by the teacher during the experiment.

____10. I had difficulty with the calculations as required on page 4.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB L2

PLEASE INDICATE THE LETTTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. After studying the Prelab Instructions I had little trouble designing my own experimental steps.

____ 2. Before performing this experiment, I understood the processes involving heat transfer in converting the vapor phase of a substance to the liquid phase (phase change).

____ 3. The laboratory instructions on pages L17 and L18 were adequate to enable me to design and perform this experiment.

____ 4. I would like to see more instructions in the laboratory manual.

____ 5. I would not care to do this experiment again, even to try and improve my results.

____ 6. I had difficulty with the Observation Report.

____ 7. I had difficulty with the Final Report.

____ 8. I believe more guidance should have been provided by the teacher during the experiment.

____ 9. I believe this experiment is too difficult for me to obtain a reasonable "heat of vaporization" value. Explain below.

____10. I believe I can improve my design and techniques in order to minimize the percent error.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB L3

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree　B - agree　C - neutral　D - disagree　E - strongly disagree

____ 1. I understood how to determine the molar heat of a phase change before doing the experiment.

____ 2. I felt confident about my determination in this experiment.

____ 3. Measuring the heat gained by an ice cube is not a very exciting or sophisticated experiment at the grade XII level.

____ 4. I found it difficult to identify what equipment, materials, and techniques would be needed for this experiment.

____ 5. Devising a method to record my data was difficult for me.

____ 6. Obtaining the quantitative data such as measuring mass, volume, temperature, etc. was not difficult.

____ 7. This experiment was not very challenging. Explain below.

____ 8. I believe more guidance should have been provided by the teacher during the experiment.

____ 9. I had some help from my fellow students in doing this experiment.

____10. I would like to do more experiments in this unit (Energy).

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back if more space is needed.

LAB M1

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. I understood the purpose of this experiment (see page 8).

____ 2. I had difficulty designing the experimental steps for the D.R.

____ 3. I had difficulty in determining whether a chemical change occurred in every case (metal + metallic ions).

____ 4. I had difficulty in recording my data (describing, tabulating, etc.) for the O.R.

____ 5. I had difficulty in ordering my data so as to identify regularities (comparing relative tendencies of metals to react and comparing relative tendencies of metallic ions to react). Explain below.

____ 6. I had difficulty completing the experiment and the O.R. before the end of period.

____ 7. I had difficulties with the questions on page 9.

____ 8. I believe more guidance should have been provided by the teacher during the experiment.

____ 9. I found the experiment interesting.

____10. I found the experiment challenging.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB M2

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. I would not like to do more experiments in this unit.

____ 2. I found this laboratory experiment more difficult than Lab M1.

____ 3. I had difficulty in designing the experimental steps.

____ 4. I had difficulty in recording my data (describing, tabulating, etc.) in the O.R.

____ 5. I had difficulty in ordering my data so as to identify regularities (i.e., finding SOA, SRA and constructing the table).

____ 6. I found it difficult to perform the experiment and complete the report before the end of the period.

____ 7. I believe more guidance should have been provided by the teacher during the experiment.

____ 8. I found the color tests with the halogens and CCl_4 confusing.

____ 9. I found this experiment interesting.

____ 10. I found this experiment challenging.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB M3

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. On page 12, Part A, fourteen steps were given under Procedure. I prefer doing laboratory experiments of this type rather than designing my own experimental steps.

____ 2. I had difficulty arriving at the endpoint in Part A (pink tinge).

____ 3. In Part B I had difficulty with the Design Report. (D.R.)

____ 4. I had difficulty organizing my data (tabulating, etc.) for the O. R.

____ 5. I [illegible] difficulty with the Final Report. (Explain below).

____ 6. I believe more guidance should have been provided by the teacher during the experiment.

____ 7. I understand not only how to use a volumetric flask (100 mL) but also the stoichiometric principle involved.

____ 8. I found this experiment difficult to perform.

____ 9. I found this experiment interesting.

____10. I found this experiment challenging.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB M4

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. I found this experiment easy to do.

____ 2. Upon connecting the voltmeter to my electrochemical cell, I generally knew which electrode was to be connected to the negative terminal of the voltmeter and seldom made an error.

____ 3. I was generally disappointed in my data.

____ 4. I prefer an experiment which has a determination or a right answer so that I know if my results are right or wrong.

____ 5. I had difficulty with the Design Report. PLease comment below.

____ 6. I had difficulty with the Observation Report. Please comment below.

____ 7. I had difficulty with the Final Report. PLease comment below.

____ 8. I believe more guidance should be provided by the teacher during the experiment.

____ 9. I found this experiment interesting.

____10. I found this experiment challenging.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB N1

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. The instructions in the lab manual were not clear.

____ 2. I had trouble designing the quantitative data for this experiment.

____ 3. I am still having trouble writing NET IONIC EQUATIONS (See prelab exercises on page 16.

____ 4. I find predicting the results of acid-base reactions by the Bronsted-Lowry theory to be difficult.

____ 5. I had difficulty with the "conflicting observations" in the F.R. See Interpretation on page 17.

____ 6. I had difficulty in organizing and recording my data for the Observation Report.

____ 7. I had difficulty explaining why all indicators did not show a color change in the F.R.

____ 8. There were too many things to do in this experiment.

____ 9. I believe more guidance should have been provided by the teacher during the experiment.

____10. I am looking forward to more experiments in this unit.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB N2

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree B - agree C - neutral D - disagree E - strongly disagree

____ 1. I am not sure that I understand the purpose of this experiment.

____ 2. I believe my titration skills have improved since Lab M2.

____ 3. I do not like to do experiments dealing with concentrations and titrations.

____ 4. There were too many things to do in this experiment and I tended to become confused.

____ 5. Without help from other students I would not have been able to do this experiment or complete the reports.

____ 6. I do not particularly like experiments where I am expected to design all the experimental steps.

____ 7. I do not completely understand the stoichiometric principle of using a volumetric flask.

____ 8. I believe more guidance should have been provided by the teacher during the experiment.

____ 9. I had difficulty with the Final Report.

____10. I found this experiment challenging.

COMMENTS

Please comment about any part of the questionnaire or any phase of the experiment. Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB N3

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree	B - agree	C - neutral	D - disagree	E - strongly disagree

____ 1. I did not feel very confident about attempting this Lab.

____ 2. I had little trouble identifying the needed equipment, materials and techniques necessary for this experiment. (DR).

____ 3. I had little trouble devising a method for recording my data (OR).

____ 4. I did not forget to repeat this experiment for reproducibility.

____ 5. I experienced few if any unexpected or accidental occurrences during the experiment.

____ 6. Upon treating my data I discovered uncertainties in my results.

____ 7. I felt confident about my determination (concentration of NH_3).

____ 8. I found many of the questions on page N52 difficult.

____ 9. I believe more guidance should have been provided by the teacher during the experiment.

____ 10. I enjoyed the challenge of trying to find the concentration of ammonia. I like this type of experiment.

COMMENTS

PLease comment about any part of the questionnaire or any phase of the experiment, Your attitude and personal feelings regarding your participation in the laboratory program are of particular interest. Please use the back of this page if more space is needed.

LAB N4

PLEASE INDICATE THE LETTER OF YOUR CHOICE TO THE LEFT OF QUESTION

A - strongly agree B - agree C - neutral D - disagree E - strongly disagree

____ 1. I had little trouble indentifying a problem.

____ 2. I felt confident about my prediction(s).

____ 3. Designing experimental steps was not difficult.

____ 4. Finding a possible explanation for the phenomena was not difficult (hypothesizing).

____ 5. This experiment was simple enough to perform yet many of the process skills studied this year were illustrated in this experiment.

____ 6. I interpreted my data verbally but I had difficulty interpreting the data mathematically.

____ 7. I believe I know more about the process skills used by scientists in research (see underlined words above) than I did at the beginning of this science course.

____ 8. Teacher guidance was not needed during this experiment.

____ 9. I found most of the experiments interesting and challenging this year.

____10. I was generally pleased with my work in the laboratory this year.

Special Question:

As a learning experience, how do you like the type of experiments you have been doing this year?

COMMENTS

Please comment about any part of the laboratory program this year.

APPENDIX I

LABORATORY QUESTIONNAIRE RESULTS

TABLE 44

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB L1

Lab L1: Molar Heat of a Chemical Change

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(not sure of molar heat)	Ct	5	20	10	65	0	3.4
2.	(still not sure)	Ct	0	10	10	75	5	3.8
3.	(not sure - specific heat)	Ct	0	0	5	40	55	4.5
4.	(density)	Ct	0	20	15	40	25	3.7
5.	(instructions clear)	Pr	0	50	35	15	0	2.6
6.	(difficulties with DR)	Pr	0	25	20	40	15	3.4
7.	(reproducibility)	Pr	15	40	10	10	20	2.8
8.	(difficulty with OR)	Pr	5	10	25	45	15	3.8
9.	(more guidance needed)	Pr, At	0	10	50	35	5	3.4
10.	(difficulty with calculation)	Ct, Pr	5	35	15	40	5	3.1

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 45

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB L2

Lab L2: Molar Heat of Vaporization

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean Response[a]
1.	(no trouble with DR)	Pr	20	55	5	20	0	2.2
2.	(phase change	Ct	15	50	15	20	0	2.4
3.	(lab instruction adequate	Pr	25	55	20	0	0	2.0
4.	(more instruction needed)	Pr, At	10	15	50	10	15	3.9
5.	(do not care to do)	At	0	10	5	40	45	4.2
6.	difficulties with OR)	Pr	10	10	20	45	15	3.5
7.	(difficulties with FR)	Ct. Pr	15	20	30	30	5	2.9
8.	(more guidance needed)	Pr, At	0	5	35	50	20	3.6
9.	(lab too difficult	Pr	0	20	30	40	10	3.4
10.	(improve results)	Pr, At	25	50	20	5	0	1.9

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 46

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB L3

Lab L3: Molar Heat of a Phase Change

Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1. (molar heat)	Ct, Pt	25	60	15	0	0	1.9
2. (felt confident)	At	20	65	5	10	0	2.0
3. (not exciting)	At	0	0	50	45	5	3.5
4. (difficulty with apparatus)	Pr	0	5	0	80	15	4.0
5. (difficulty with OR)	Pr	0	0	10	65	25	4.2
6. (no difficulty with data)	Pr	15	80	0	5	0	1.9
7. (not challenging)	At	0	35	30	30	5	3.0
8. (more guidance needed)	Pr, At	0	0	15	70	15	4.0
9. (had help from peers)	Pr	0	40	10	45	5	3.1
10. (like to do more experiments)	At	10	40	45	5	0	2.5

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 47

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB M1

Lab M1: Introduction to Redox

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(purpose)	Pr	50	45	0	5	0	1.6
2.	(difficulty with DR)	Pr	0	15	5	50	30	4.1
3.	(observing change)	Pr	0	15	0	55	30	4.0
4.	(difficulty with OR)	Pr	0	10	10	45	35	4.2
5.	(difficulty with ordering)	Pr	0	15	15	50	20	3.8
6.	(difficulty completing)	Pr	10	40	0	20	30	3.1
7.	(difficulty with questions)	Ct, Pr	0	10	25	55	10	3.6
8.	(more guidance needed)	Pr, At	5	10	5	40	40	4.0
9.	(interesting experiments)	At	20	65	15	0	0	1.9
10.	(challenging experiments)	At	5	20	60	15	0	2.9

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 48

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB M2

Lab M2: Introduction to Redox

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(would not like to do)	At	0	0	10	75	15	4.1
2.	(lab more difficult)	Pr, At	5	50	5	25	15	3.0
3.	(difficulty with DR)	Pr	0	5	15	45	35	4.1
4.	(difficulty recording)	Pr	5	10	15	40	30	3.8
5.	(difficulty ordering)	Pr	10	15	10	50	15	3.2
6.	(difficult to finish)	Pr	0	15	10	35	40	4.0
7.	(more guidance needed)	Pr, At	0	0	15	55	30	4.2
8.	(color tests confusing)	Pr	5	35	25	35	0	2.9
9.	(interesting experiment)	At	15	60	20	5	0	2.2
10.	(challenging experiment)	At	15	50	20	15	0	2.4

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 49

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB M3

Lab M3: Redox Titration

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(prefer ALCHEM experiment)	At	0	25	25	50	0	3.3
2.	(difficulty with end point)	Pr	5	10	30	50	5	3.4
3.	(difficulty with DR)	Pr	0	15	5	70	10	3.8
4.	(difficulty with OR)	Pr	0	20	20	50	10	3.5
5.	(difficulty with FR)	Pr	25	20	35	20	0	2.5
6.	(more guidance needed)	Pr, At	0	15	20	60	5	3.6
7.	(stoichiometry)	Ct, Pr	15	45	10	30	0	2.6
8.	(difficult to perform)	Pr	15	35	15	35	0	2.7
9.	(interesting experiment)	At	5	80	15	0	0	2.1
10.	(Challenging experiment)	At	30	60	10	0	0	1.8

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 50

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB M4

Lab M4: Electrochemical Cells

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean Response[a]
1.	(experiment easy to do)	At	5	50	30	15	0	2.6
2.	(voltmeter connections)	Ct, Pr	40	55	5	0	0	1.6
3.	(disappointed in data)	At	10	45	20	20	5	2.6
4.	(prefer experiment with answer)	At	10	15	45	25	5	3.0
5.	(Difficulty with DR)	Pr	0	5	30	65	0	3.6
6.	(difficulty with OR)	Pr	0	0	20	75	5	3.9
7.	(difficulty with FR)	Pr	0	10	30	55	5	3.6
8.	(more guidance needed)	Pr, At	0	5	15	70	10	3.8
9.	(interesting experiment)	At	15	80	5	0	0	1.9
10.	(challenging experiment)	At	20	50	30	0	0	2.1

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 51

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB N1

Lab N1: Bronsted-Lowry Reactions

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(lab manual not clear)	At	0	10	5	55	30	4.0
2.	(difficulty with DR)	Pr	5	10	10	65	10	3.7
3.	(difficulty with equations)	Ct	0	5	5	60	30	4.2
4.	(theory difficult)	Ct	0	20	15	55	10	3.6
5.	(difficulty with FR)	Pr	0	0	15	70	15	4.0
6.	(difficulty with OR	Pr	0	5	20	60	15	3.9
7.	(difficulty with indicators)	Pr	10	40	5	45	0	2.8
8.	(too many things to do)	At	10	10	15	60	5	3.4
9.	(more guidance needed)	Pr, At	0	5	15	50	30	4.0
10.	(more experiment in this unit)	At	15	40	45	0	0	2.3

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2 ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 52

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB N2

Lab N2: Standardization Titration

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(purpose not understood)	Ct, Pr	0	5	20	65	10	3.8
2.	(skills improved)	Pr	20	60	5	15	0	2.2
3.	(do not care to do)	At	0	5	25	60	10	3.8
4.	(too many things to do)	Pr	0	0	10	90	0	3.9
5.	(had help)	Pr	0	10	25	45	20	3.8
6.	(do not care to design)	At	0	5	30	50	15	3.8
7.	(principle not understood)	Ct, Pr	0	10	15	50	25	3.9
8.	(more guidance needed)	Pr, At	0	5	10	65	20	4.0
9.	(difficulty with FR)	Ct, Pr	0	30	10	55	5	3.4
10.	(challenging experiment)	At	20	65	10	5	0	2.0

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 53

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB N3

Lab N3: Titration - NH_3

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean[a] Response
1.	(did not feel confident)	At	0	5	15	80	0	3.8
2.	(no difficulty with DR)	Pr	10	55	10	15	10	2.6
3.	(no difficulty with OR)	Pr	20	65	5	5	5	2.1
4.	(reproducibility)	Pr	35	55	0	0	10	2.0
5.	(nothing unexpected)	Pr	0	80	10	10	0	2.3
6.	(uncertainties in results)	Pr	0	25	40	35	0	3.1
7.	(confident about results)	At	10	20	35	35	0	3.0
8.	(questions difficult)	Ct	10	55	20	20	5	2.4
9.	(more guidance needed)	Pr, At	0	10	15	60	15	3.8
10.	(like the challenge)	At	25	35	40	0	0	2.2

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

TABLE 54

PERCENT RESPONSES FOR LABORATORY QUESTIONNAIRE LAB N4

Lab N4: Common Ion Effect

	Question Descriptor	Domain[b]	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean Response[a]
1.	(problem no difficulty)	Pr	5	20	10	65	0	3.4
2.	(confident with prediction)	At	5	40	30	15	10	2.8
3.	(no difficulty with DR)	Pr	10	80	5	5	0	2.0
4.	(not difficult to hypothesize)	Pr	0	45	25	25	5	2.9
5.	(process skills - all)	Pr	10	65	15	10	0	2.2
6.	(interpreting difficult)	Pr	30	50	10	5	0	1.9
7.	(know more process skills)	Pr	40	55	5	0	0	1.6
8.	(guidance not needed)	Pr, At	15	65	10	10	0	2.2
9.	(interesting and challenging)	At	40	55	5	0	0	1.6
10.	(pleased with year)	At	25	55	20	0	0	2.0

[a] Means were calculated on the basis of Strongly Agree=1, Agree=2, ..., Strongly Disagree=5

[b] Ct stands for Concept, Pr for Process and At for Attitude

APPENDIX J

CRITERIA FOR EVALUATION OF LABORATORY REPORTS

CRITERIA FOR EVALUATION OF LABORATORY REPORTS

DESIGN REPORT (DR) (5 marks)

a. Experimental steps must be original within limitations given.

b. Experimental steps are to be both qualitative and quantitative.

c. Quantitative statements are to be expressed to the correct number of significant figures (determined by limitation of equipment).

d. Experimental steps are to be logically sequenced.

OBSERVATION REPORT (OR) (5 marks)

a. The report is to show evidence of organization or structure.

b. Data must be tabulated. (table, matrix, headings and sub-headings)

c. Each trial is to be labelled.

d. Recorded data are to be consistent with the DR.

e. Changes in experimental procedures different from the design should be indicated on the back of the OR.

f. Data are to be expressed to the correct number of significant digits.

FINAL REPORT (FR) (10 marks)

a. Balanced equations for all reactions are to be included.

b. Design steps and recorded data need not be included in the FR.

c. All questions in the laboratory exercises are to be answered in the FR.

d. Only one determination, which should be the average for all trials, and only one per cent error is to be submitted.

e. Calculations for all trials are to be included.

f. Sources and amount of error are to be included.

g. Interpretations must include a discussion of findings: achievement of purpose, explanations, generalization, validity of assumptions, delimitations, omissions, and comments about the quality of work.

APPENDIX K

MEANS, STANDARD DEVIATIONS, AND PERCENT ERRORS FOR EXPERIMENTS WITH DETERMINATIONS

TABLE 55

MEANS, STANDARD DEVIATIONS, AND PERCENT ERRORS FOR EXPERIMENTS WITH DETERMINATIONS

Lab No.	Accepted Value	Class Determination	Standard Deviation	Percent Error
L1	57.0	48.7	3.9	15
L2	40.8	29.6	8.8	28
L3	6.03	5.52	1.3	8.5
M3 (Part A)	0.00800	0.00831	0.00047	8.6
M3 (Part B)	0.023	0.0245	0.0032	6.1
N2	0.180	0.186	0.014	3.2
N3	0.130	0.132	0.051	1.5
	$\overline{X}$ (Mean Percent Error)			10.0

APPENDIX L

SUMMARY OF STUDENT RESPONSES OF TAPED INTERVIEWS

TAPED INTERVIEW QUESTIONS

Two students, randomly selected, were interviewed after each laboratory investigation. These interview sessions were tape-recorded and each interview lasted approximately thirty minutes. The questions below are those which formed the structured section of the interview. Depending on how students answered the questions, other more indepth questions were usually asked.

QUESTIONS

1. How do you feel about this laboratory investigation? What did you like about it? What features? Why?

2. Tell me about your thoughts and feelings on the following:

   (a) the topic investigated. Did you understand the purpose?

   (b) prelab discussions. Were they adequate? Why?

   (c) design and observation; processing and interpreting data.

   (d) laboratory reports (DR, OR, FR). How do you feel about writing three reports rather than one?

   (e) marking reports.

   (f) your peers and the teacher. What effect did your classmates and the teacher have on the classroom setting?

3. How can this course be improved?

TABLE 56

Summary of Student Responses of Taped Interviews on Lab L1

Questions	Responses
1. General Feelings about Lab	Not difficult/ Not very complicated/ Fun to do/ Interesting/ I understood what I was doing// I particularly enjoyed lab, especially writing my own procedures/ I liked being trusted . . . not having to follow a [given] procedure/ I enjoyed lab but I had a little problem with calculations.
2. Opinions on:	
(a) Topic (Purpose)	At first I didn't know what it was about/ Yes, I know now// Purpose was clear/ Interesting . . . so much heat given off.
(b) Prelab Discussion	Everything was straingt forward before I went into the lab// That was good/ Prelab was very helpful/ I got a lot from discussions.
(c) Design, Observation, Processing, Interpreting Data	Not hard to write up/ I knew what to do/ OR was simple enough, although I wish I had known that we were supposed to do more than one trial/ Processing was more difficult// DR was faily easy because of prelab/ OR was fairly easy because I understood the lab/ Processing data was mor difficult because I didn't know the order/ The interpretations and processing part was the most difficult . . . we should have gone over this in class first.
(d) Writing Reports	I like the idea of handing in three reports/ You have to think before going into the lab// A little more work but I guess it is better for us.
(e) Marking Reports	Fair//
(F) Peers and Teacher	Good atmosphere/ I know I can ask the teacher or others for help/ Although the teacher didn't help us during the first lab// Students didn't feel pressured in the class/ Not afraid to speak out/ Relaxed atmosphere/ Teacher takes time to explain things/ Students feel good about going to Chem 30
3. Improving Lab Program	I can't think of too many things right now/ Maybe more help with calculations.

TABLE 57

Summary of Student Responses of Taped Interviews for Lab L2

Questions	Responses
1. General Feelings about Lab	I thought this lab was rather inaccurate . . . because of loss of steam/ I found lab relatively easy to set up and do// You learn more this way/ You learn about your own mistakes/ We should have more time to plan.
2. Opinions on: (a) Topic (Purpose	Kind of interesting but I don't think I would ever use it in my everyday use// I didn't see any thing practical in this lab/ Purpose was understood.
(b) Prelab Discussion	It was quite useful// More information given and since this was the second lab, we were more at ease.
(c) Design, Observation, Interpreting Data	No difficulty with DR or the OR/ At first calculations gave a high percent error . . . had correct calculations after all// No problem.
(d) Writing Reports	Better (than Gr. X or Gr. XI)/ It allows you to do things in steps/ It sums up the whole lab// A lot more work but in the long run you learn more.
(e) Marking Reports	I liked my grade but I had put a lot of work into the lab and I thought the mark reflected the work// I don't think you were marking too hard on the first lab/ I got a poor mark but it was because I didn't know what was going on . . . I was away for the prelab discussions.
(f) Peers and Teacher	This class is easy to get along with/ I think I am learning enough/ The class is quite enjoyable/ Teacher lets us give our points of view/ I must do better . . . the teacher is doing his job// The atmosphere in Chem 30 is good/ No tensions like in some classes/ People can joke with the teacher/ This class is interesting and I find it enjoyable.
3. Improving Lab Program	We need more practice with labs like this one// The experiments we have to do should work out a little better/ My percent error was too high.

TABLE 58

Summary of Student Responses of Taped Interviews for Lab L3

Questions	Responses
1. General feelings about Lab	In general it is more interesting to do a lab this way/ It is more of a challenge this way/ You find out what you really know if you have to do it yourself/ This lab didn't look like much of a lab at first--just crushing ice . . . but there is more to it than meets the eye/ It was interesting// I like doing labs this way/ I don't like having to follow all kinds of directions/ It's difficult for me to figure out what I am supposed to be doing/ Easy lab to set up/ I had a high percent error . . . I don't know what happened.
2. Opinionn on:	
(a) Topic (Purpose)	I don't know--I guess it is interesting to figure out how much heat is required to melt ice// It didn't seem too interesting at first--just ice/
(b) Prelab Discussion	Going over what you did the day before helped// It was sufficient/ It didn't tell us why . . . but it told us enough.
(c) Design, Observation, Processing, Interpreting Data	The FR is the report I find difficult/ I think we all find calculations difficult// Yes I changed my design while doing the lab/ I crushed the ice and dried it before dropping it in/ Also tried to weigh ice before it melted--impossible.
(d) Writing Reports	No trouble with OR or organizing/ No trouble with calculations/ I like this system better// This is much better because you're not considering everything all at once//
(e) Marking Reports	Fair/ I made a lot of mistakes// Adequately marked/ The red ink helped a lot for the next lab.
(f) Peers and Teacher	Yes we help each other/ We always enjoy doing labs/ We are doing these labs on our own and we seem to be free to do what we want to do/ This leads to better understanding of what you're doing// This class is a challenge and I like a challenge/ I like to do things for myself/ I enjoy the class.
3. Improving lab Program	No, not really.

TABLE 59

Summary of student Responses of Taped interviews on Lab M1

Questions	Responses
1. General Feelings about Lab	I didn't like this lab much. We had just started this unit and this lab didn't make much sense at first/ I like the freedom . . . if you make mistakes you are free to change/ I don't like the idea of being rushed . . . not enough time to change anything and do it over// I am getting used to this type (of lab) after doing a few. The first three labs seemed more interesting/ This one was more like Chem 20.
2. Opinions on:	
(a) Topic (Purpose)	It was quite interesting but I guess I didn't understand about the table/ Interesting, I understood the purpose.
(b) Prelab Discussion	You left out the matter about the table// For me it was enough.
(c) Design, Observation, Processing, Interpreting Data	Doing the observations right after the lab is good . . . I don't like having to hand in the report right away--not enough time for me. Interpreting data is most difficult// I sort of enjoyed the design. Observations were easy/ The other labs were harder.
(d) Writing Reports	I am not sure which system I like better. I haven't done enough to compare// I would rather do three reports. Maybe it doesn't make any difference.
(e) Marking Reports	I would say you're fair but I would not say you're easy// I am satisfied/ I can see why you mark the way you do/ I think it's pretty fair compared to some of the teachers.
(f) Peers and Teacher	You are a "fuss-pot" about details. I really enjoy the class. When other people ask questions they help me get involved/ I don't feel dumb about asking questions. I like to get involved and I want to/ You seem to really enjoy your job and you get involved with the students/ Sometimes you rely too much on the smarter students for answers. That's okay. YOu seem fair as a teacher// Someone asking questions makes it better for me. In the lab you don't really say very much and you don't interfere with us/ In class the atmosphere is good and I enjoy the class/ It was one of my favorite and I shall remember my grade twelve because of it.

TABLE 60

Summary of Student Responses of Taped Interviews on Lab M2

Questions	Responses
1. Generl Feelings about Lab	I found this lab interesting although I wasn't too sure about the color test at first// It was good lab. I understood more . . . Before the lab I was worried about what would happen. I feel that way before each lab. I should learn from my mistakes.
2. Opinions on:	
(a) Topic (Purpose)	The purpose was interesting although the lab was somewhat the same except we didn't know the species this time. This made it interesting// The purpose was good. I can see what the scientist who made up the table went through too.
(b) Prelab Discussion	Adequate except for the color test. Once I got going I knew what to do, however// It was adequate--you don't want to give too much information away.
(c) Design, Observation, Processing, Interpreting Data	I like designs. Especially the lab on molar heat of steam--I felt like a scientist! The DR and OR are easy but FR is more difficult// This type of lab is a lot harder(than ALCHEM). Observations are easy but processing data can be difficult sometimes. This lab wasn't too bad. In the FR you have to say something to show you know what is going on.
(d) Writing Reports	I like this system better. You can take more time to figure out what you are going to do and how you are going to do it// The old way was easier. But you didn't know what it was all about. It is sort of like taking the lab apart. It is a better way.
(e) Marking Reports	I like this way of marking. It's fair// Sometimes you get a little picky. My marks are one of the lowest in the class but I do think you are marking fair. I have no complaints.
(f) Peers and Teacher	I like this class and I like the teacher. I can understand what is going on. The class is more interesting// I feel we are competing with each other. But for the most part my peers don't seem to affect me much. As for the teacher I definitely like the way you teach. In Grade X and XI kids had a sort of negative attitude but in Chem 30 they seem more serious. The teacher affects my attitude more than my peers in this class anyway.

TABLE 61

Summary of Student Responses of Taped Interviews on Lab M3

Questions	Responses
1. General Feelings about Lab	The stoichiometry in M3 was a little more difficult. I think the way we are doing labs now is more beneficial. I didn't know how much to titrate the first time. It was tedious . . .// I found it rather fascinating. The color changes being accurate, precise, reading the buret. Interesting. This lab was more challenging than some of the other labs. Some parts of the lab were a little monotonous but it was all necessary.
2. Opinions on:	
(a) Topic (Purpose	Purpose was OK// Interesting. It was more involved. [Why?] Well you had to make a primary standard and it had to be right because it would affect the second part.
(b) Prelab Discussion	If we had been told how much to use in this first titration I wouldn't have been so rushed for this lab// The half hour the day before sure helped to practice our titrating skills. I thought the prelab was adequate.
(c) Design, Observation, Processing, Interpreting Data	Design and observation were not bad. The calculations were difficult until I caught on. Once the molar concentration was worked out it was OK// The design was very challenging. It was a good thing this was not the first lab--at this stage of the year it was OK--we were more familiar with designs. The FR and OR were not that difficult but the DR was the most challenging . . .
(d) Writing Reports	(Half of this lab you were told what to do while the other half you were not. How would you compare the two parts) Yes, Part A was like being back in Grade X--you were told what to do. [Which part did you find easier?] They were about the same// I think this is a great system for doing labs. Last year I came to lab not prepared, not knowing what to do but now you forced us to know what's going on. It certainly makes me put more time in the labs. I know I spend more time. When you have to design you take a little more pride in designing your own thing, instead of following someone else's direction. I sort of like to be independent and draw up my own.

TABLE 61 (Cont'd)

Summary of Student Responses of Taped Interviews on Lab M3

Questions	Responses
(e) Marking Reports	I liked this better than [last year], My mark was not high but it was fair// This one was marked fairly. In this lab it was OK but in the first lab you were a little picky about significant digits. I can't really complain. I can see where I lost marks when I started to read into the lab instead of sticking to the data I got.
(f) Peers and Teacher	I liked being in this class. I liked what was going on. The teacher was OK, The class was different. You seem to care about us. It has a personal effect on us// This class is a lot more free than a lot of other classes I have been in. You encourage discussion among students; for instance, that day you gave us a problem . . . then instead of letting us tell you the answer you had . . . that was very interesting. Coming into this class I was a little worried . . . but after a few classes my anxiety went away. I feel one of the best things you do is to encourage students to speak out. I sure have no complaints about the teacher.

TABLE 62

Summary of Student Responses of Taped Interviews on Lab M4

Questions	Responses
1. General Feelings about Lab	I thought this lab was pretty good. It related a lot of electrochemistry for me.
2. Opinions on:	
(a) Topic (Purpose)	The topic was very good . . . the EMF's were not pulled out of a hat. They actually can be proved experimentally.
(b) Prelab Discussion	It was self-explanatory. Adequate.
(c) Design, Observation, Processing, Interpreting Data	I enjoyed the design part. You learn more about the lab because you have to think about it before going into the lab. Easy to record. [Did you have trouble organizing data?] This lab was more difficult but most of the labs are easy to do. Once the DR and OR are done it's pretty easy to do the interpreting and processing.
(d) Writing Reports	I prefer doing it this way. You do learn a lot more when you do it yourself, although sometimes you do need help or you will be more confused. I prefer doing it on my own rather than have everything laid out for me because things aren't laid out for you . . . like going to university or when you're out on your own.
(e) Marking Reports	My marks have been good. I think they are marked easy.
(e) Peers and Teacher	I enjoyed our class. Each person has their own views and not afraid to express them. Everyone is participating. I think [the teacher] he is a very good teacher because he doesn't just stick to blackboard chemistry. He gets everyone involved. [What about all labs in general?] The titrating one was very interesting. [Why?] It has a lot of work in it . . . it posed more problems.

TABLE 63

Summary of Student Responses of Taped Interviews on Lab N1

Questions	Responses
1. General Feelings about Lab	It was very interesting. This was the first lab in a new unit and the first lab is usually harder than the rest. I knew after the lab what indicators were all about. In these labs you have to be able to understand the information. The system forces you to learn in order to do the lab// I generally understood what was going on before going into the lab. Predicting was kind of interesting. This way you have to understand it before going into the lab. You know what you have to do.
2. Opinions on:	
(a) Topic (Purpose)	Unique. In previous grades the theory didn't seem to apply to real life. The purpose was interesting because the predictions and the observations didn't always follow each other. [Explain] Well, before if things didn't work out the teacher just pointed out why. Here, we have to explain the difference why. Here, we have to explain the difference between theory and observations// The purpose was to illustrate everything we studied and within certain limits it did.
(b) Prelab Discussion	Adequate// Adequate for this lab. We understood the theory.
(c) Design, Observation, Processing, Interpreting Data	Designing is better than being told but it is not [easy]// Designing or recording were not problems. I didn't understand why some reactions didn't work. I understood those that did work.
(d) Writing Reports	I like this one better. A better way to learn and easier to learn// I prefer this way. It is a good way of organizing yourself. I didn't see much sense in doing labs the way we used to [previous grades].
(e) Marking Reports	You were fair in all cases// Good, though the teacher is a little fussy sometimes. It doesn't hurt.

TABLE 63 (Cont'd)

Summary of Student Responses of Taped Interviews on Lab N1

Questions	Responses
(f) Peers and Teacher	There's a good atmosphere and I like the competition. You seem to enjoy teaching us and everyone gets involved and promotes learning// The Teacher gets really excited about things sometimes and makes it pretty interesting and that keeps (one) interested. Some of my peers make it harder for me. They seem to understand it a lot better than me. This makes it harder for me. But I like this system better. My classmates help me. But at least I understand what I'm doing and it ties in with the unit.
3. Improving Lab Program	Yes, cut down on the number of labs. Some of the subjects should be investigated [pursued] in more detail.

TABLE 64

Summary of Student Responses of Taped Interviews on Lab N2

Questions	Responses
1. General Feelings about Lab	I believe this program is a lot better than in past years. This wasn't very difficult but it kept your interest.// I liked the experiments we did this year because we were given a chance to think about what we were doing . . . last year we were told what to do. We were told somethings in this lab but it was kind of challenging and made it more interesting. I didn't like the fact that we were not given the final concentration so we could figure out what we did wrong or have an idea [about the concentration]. I guess that made it all the more challenging. The lab experiments seem to be important this year.
2. Opinions on:	
(a) Topic (Purpose)	The purpose was straight forward but difficult to carry out. It was interesting// A good experiment . . . it took a lot of skills to do the experiment.
(b) Prelab Discussion	Quite adequate. The lab was straight forward and not as much was needed as in the other labs// Adequate. No question about what we should do or should not do.
(c) Design, Observation, Processing, Interpreting Data	Because we made the design we knew exactly what to do. I had no problem and I found the processing easy. This was a warm-up for Lab N3// [Few] problems with the design and I got a very small percent error so I must have been doing somethings right. I had [few] problems with the interpretations since earlier this year we had been shown the principle that was needed in this experiment.
(d) Writing Reports	More interesting than Chem 10 & 20 but getting the OR done before the end of the period was difficult but generally there is enough time if you watch it// I like this system better. In order to write it up we had to know what was involved. Handing in the observation report at the end of the class forced you to use the results that you obtained in class. You weren't able to change them.
(e) Marking Reports	Generally fair. Your remarks helped// Marking was fair.

TABLE 64 (Cont'd)

Summary of Student Responses of Taped Interviews on Lab N2

Questions	Responses
(f) Peers and Teacher	Some students want to make the lab harder than it really is. [Explain] They ask a lot of questions which do not have (any bearing) on the lab, and this does more to confuse me because I hadn't thought about it. You didn't have much to do with the lab part, that is, you let us do it the way we wanted to although in this lab you pointed out that our techniques were poor and you helped us this time. [What do you think about that?] It's quite good. You also let us make mistakes and don't interfere. That's good. If you make a mistake then the next time you have a chance or remembering . . ./// My peers helped with the course. The teacher wouldn't help us with the FR and would not answer any questions. This forced us to think for ourselves and not just do what we were told.

TABLE 65

Summary of Student Responses of Taped Interviews on Lab N3

Questions	Responses
1. General Feelings about Lab	Pretty interesting, not like Chem 10 & 20. I think you can learn more about labs by doing them on your own. You had to apply what you had learned previously and it put more pressure on me to see if I could get the expected results. This is a better way to do labs// I find titrations interesting. Easy to understand and to follow. [Why do you like titrations?] You have to be very accurate and I get a feeling of satisfaction when I do it right. I like to design and record the way I want to.
2. Opinions on:	
(a) Topic (Purpose)	Good excep I was (worried) about applying my results (from N2) to this lab. It was interesting// It was a little more complex--more things to think about.
(b) Prelab Discussion	As the year progresses we are being told less and less. We are able to do more of it on our own. The results that most of the students got were very accurate so this proves that everyone knew what was going on at least// No prelab was necessary because it was just an extension of the lab we had previously. For most of the other labs it was adequate but sometimes it was little short of what I expected. Usually by the end of the lab I knew what was going on.
(c) Design, Observation, Processing, Interpreting Data	The design is a good idea. You had to read and understand before . . . The observations didn't always turn out the way I expected them to. I had trouble with the processing// No trouble with the design and the observation was easy to fill in. I usually had trouble with the interpretations. I don't always know what you want. I don't have trouble with the math usually.
(d) Writing Reports	I like the three reports--you get a much better idea of what's going on// I prefer this system. It sets apart three different states of the work. It is a more organized way to do it.
(e) Marking Reports	I didn't really like the mark I got on this lab but it was fair. The other labs were marked fairly; and even though results are "way off" if the work is correct you can still get good marks. Yes, I think it is a good way of marking// I thought you were generous on this lab but on some of mine I thought you were a little stingy and a little picky.

TABLE 65 (Cont'd)

Summary of Student Responses of Taped Interviews on Lab N3

Questions	Responses
(f) Peers and Teacher	Sometimes it was frustrating and you could ask them (peers) for help. I found it frustrating going into the lab and not knowing what was going on and then the teacher would not help. Except it was better in the long run. It puts more responsibility on us to know about the labs. I got better as the year progressed. It was quite a change from getting everything given to us to having to interpret on our own// My peers gave me a positive attitude. The teacher affected my attitude in a positive way and because he expected us to think . . . If you had taken a (lesser) role, I might not have thought about things or tried to put out as much. It was because of your (expectations).
3. Improving Lab Program	More emphasis should be placed on the purpose// I think grade twelve is a bit late to start a program like this. You should start in Grade X or in junior high.

TABLE 66

Summary of Student Responses of Taped Interviews on Lab N4

Questions	Responses
1. General Feelings	I liked this lab. It's interesting to do a lab where you don't have a specific problem and you have to find it yourself. It can be kind of frustrating too. This time we weren't given much to formulate our own hypotheses. Nothing was given here and this was interesting to go all the way through and find it yourself.
2. Opinions on:	
(a) Topic (Purpose)	The topic was interesting but purpose was somewhat vague. There was not much to actually doing the lab but the prediction was more interesting and challenging.
(b) Prelab Discussion	The prelab was adequate. You can't discuss it too much because that's what you're trying to do. You're trying to find that theory by yourself.
(c) Design, Observation, Processing, Interpreting Data	The hyposthesis and the predictions were pretty interesting. DR and OR were easy to do, but after discussing it in class today I guess I missed a few things. Processing the data was not too difficult for me because the data fitted my hypothesis just the way I predicted it would. I interpreted my data verbally. I couldn't do it mathematically. I didn't make too many assumptions.
(d) Writing Reports	I like this system this year. You get a better understanding of what you're studying. Yes, it is more work and more frustrating but the work pays off and my marks have improved.
(e) Marking Reports	I was pretty satisfied with the marks this year up to Lab N2 and N3. The one depended on the other. I guess I deserved to be docked.
(f) Peers and Teacher	I liked chemistry this year. We (peers) worked well together. It was a pleasant class to come to--there were no conflicts and no real worry. I enjoyed it.

APPENDIX M

SUMMARY OF WRITTEN COMMENTS

TABLE 67

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB L1

Lab L1: Molar Heat of Chemical Change

Student	Written Statements
01	Because this was the first lab I was unsure of what I was doing. I should have studied more theory and asked more questions before lab.
02	I think it is good that so much of the planning is left to us.
03	n/a*
04	I am confused about how to find the molar heat of a reaction.
05	I liked the way we were allowed to set our own experiments. for the first lab we should have processed data together.
06	This lab was more enjoyable and demanding than ALCHEM 20.
07	I had difficulties with calculations. This type of lab helps.
08	I enjoyed doing labs that I designed. But I am used to Chem 10-20 type of labs.
09	I got a large percent error. I found the calculations hard. I enjoy doing labs this way.
10	I had difficulty with the Final Report. I enjoy being able to plan the lab myself, although it is more difficult this way.
11	I had some problems in the lab because it is a change from (Chem 10-20). It is good to let us do most of the work but at this time some guidance is needed. I had a hard time trying to find out what we are looking for . . . it wasn't spelled out like it usually is.
12	I was not sure how to organize the Final Report.
13	Lab itself was not difficult but calculations were. I enjoyed being given the opportunity to do (design).
14	Lab not too difficult but the calculations were confusing at first.
15	I would appreciate more guidance for processing data. Designing was OK.
16	I found it hard to decide what really was required because I was used to everything being given to us.
17	Of all the Chem labs I have done through high school this is the one I put the most thought into because I had to design the experiment. I would like at least one class between OR and DR to ask questions.
18	I had little difficulty with DR and OR but did with FR.
19	Setting up our own labs is great, but it seems hard now because I have never done it before. Guidance should be given for at least one more lab.
20	I was not sure what to include in OR, I had difficulties with calculations.

*n/a means not applicable

TABLE 68

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB L2

Lab L2: Molar Heat of Vaporization

Student	Written Statements
01	I will have to improve my design to eliminate error.
02	I think I know how to do it but I'm not certain.
03	More time is needed to try again with new improvements.
04	I believe I could eliminate high error with a new design and redoing.
05	More trials would improve my results.
06	The experiment was difficult with the suggested apparatus. I am still having trouble with calculations.
07	n/a*
08	I had difficulty with calculations.
09	This lab was confusing at first but once organized it wasn't too bad.
10	The hardest part was setting-up. The calculations were easy but produced a high percent error.
11	n/a
12	I would like to try again to get better results.
13	If we had proper equipment, it would not be too difficult.
14	We had a high percent error. We realized it was due to steam condensing.
15	After looking over the results, we could not figure out the right way to calculate.
16	Lab was not too difficult. The first trial did not give reasonable results. After changes in design the results became quite reasonable. It is better to find this out during the lab rather than have it pointed out. The way the lab is set up now is good.
17	This lab was much easier to do and understand than Lab L1. Perhaps I was more familiar with the work, and instructions given in the pre-lab were straightforward.
18	The apparatus was difficult to properly adjust. I had trouble with calculations.
19	Lab was not necessarily difficult but inaccurate. Steam was lost.
20	n/a

*n/a means not applicable

TABLE 69

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB L3

Lab L3: Molar Heat of Phase Change

Student	Written Statements
01	This experiment was not a flashy one, but it allowed us to see laws.
02	Not very exciting but helps us understand principle.
03	It seemed easy enough but I would like to perform experiment over again. After I found out what they were about, I like to compare.
04	Even though it was just melting an ice cube, it is the theory and trying to be accurate that makes it challenging. We get some idea of molar heat in a practical situation.
05	The lab may not have been very challenging but it required that the procedure was well known and instruments used carefully.
06	Lab a little easy. However, it helps us--builds confidence, enables us to become more efficient doing labs.
07	I felt more confident doing this lab. It was easier because we had done two similar ones. Should do more in this unit.
08	This lab wasn't too bad but I preferred Lab 2. I would like to redo Lab L2 to get better results.
09	Lab was not hard to carry out but it did involve many basic skills. I am becoming more confident and things are running smoother. It was interesting.
10	Not too difficult but the principle of molar heat was illustrated.
11	Although more challenging, I now know what a phase change is.
12	Performing the lab was not difficult but evaluating data was challenging. There is more to it than there seems to be.
13	Not too complicated but there should be more experiments in this unit.
14	The results were not very accurate.
15	I felt more confident about doing this lab.
16	The lab was as challenging as a person doing it wanted it to be. I would like to repeat Lab L2 not because I don't understand the principle involved but to get better results.
17	I forgot to account for the energy change of the melted ice . . . everything else was OK.
18	After doing Lab L1 and L2 this was easy.
19	This was easy to perform. I was surprised to find I had a high percent error.
20	n/a*

*n/a means not applicable

TABLE 70

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB M1

Lab M1: Introduction to Redox

Student	Written Statements
01	I did not realize the significance of the table we made up in this lab and the Reduction Potential Table.
02	n/a*
03	The experiment was easy and didn't seem like much until you explained the table and the spontaneous reactions.
04	Easy enough but I could have used more time.
05	Interesting. I found the experiment challenging.
06	Easy enough, although I missed recording a spontaneous reaction.
07	An easier experiment than the previous ones on energy. I needed more time, however.
08	I did not realize at the time that the ions and metals could be placed in a table that was like the Reduction Potential Table.
09	n/a*
10	No trouble recording data but the catch is this lab is to go beyond the problem when interpreting the data.
11	Easy to understand and follow.
12	n/a
13	n/a
14	The experiment was straight forward and easy to follow.
15	This lab did not seem very complex.
16	More guidance was necessary before the lab. We didn't know much about OA and RA before this lab.
17	Easy to do but I didn't finish in time because I was disorganized at the beginning. Not too difficult to interpret data.
18	Easy.
19	There were few sources of error. Easy to do.
20	n/a

*n/a means not applicable

TABLE 71

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB M2

Lab M2: Electrochemistry - Spontaneous Reactions

Student	Written Statements
01	Determining the agents was difficult to do. We had no method.
02	Lab was very interesting. I am sure I tabled my results correctly.
03	It was easy to make mistakes in OR and in interpretations.
04	Basically the same as M1 but a lot more challenging.
05	Not knowing what solutions we were actually using made the experiment interesting and the outcomes were (unpredictable). It was more challenging to do the experiment correctly.
06	Good application of theory learned prior to lab. Color test confusing.
07	The color tests were confusing in this lab. It was interesting to see the color changes.
08	The color tests were confusing.
09	This was a very mysterious experiment--not knowing the solutions.
10	I had trouble interpreting my data because I didn't really understand the use of the reduction potential table when I wrote the FR.
11	This experiment was a little more challenging (than M1) because you had to figure out which were the agents.
12	n/a*
13	I was confused with the color tests.
14	It was difficult to do the design report without knowing what was supposed to happen. After learning about the color tests the lab was less confusing. I found it interesting to try and figure out the agents.
15	I wasn't exactly sure how to process my data because of the color tests.
16	Usually we are told what to do and how to do it. We had to think in the FR. This was good.
17	It would have helped to have the color tests explained first. I was confused at the time of the experiment.
18	The procedure was fairly straight forward. I found the FR most difficult. I didn't know what the reactants were.
19	I am beginning to see more how to do these experiments on my own and how to design the labs. Teaches a person to think on his own.
20	This lab was quite easy to perform. The color test confused me at first.

*n/a means not applicable

TABLE 72

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB M3

Lab M3: Redox Titration

Student	Written Statements
01	Designing your own steps is not as easy as (conventional) labs but you learn more.
02	I would rather write my own steps because it is easier to remember what to do next. I had trouble with the final report.
03	I like the procedure given but I like to make changes if and when necessary.
04	I prefer to follow steps that are given for the first lab in a new unit but for (subsequent) labs in that unit steps are not needed.
05	This experiment was interesting because it was different from others.
06	Too little time to set-up the experiment.
07	I need more time on the buret and pipette. We should have another lab.
08	I found this lab challenging and I had trouble with FR but after some reading I understood how to calculate the concentration.
09	The lab was easy to perform but I had trouble with interpretations.
10	The lab was challenging. I had trouble pipetting.
11	This lab was challenging and difficult. More prelab was necessary.
12	The lab was confusing at first but after the lab I realized how to do the calculations and the Final Report.
13	I enjoyed this lab. It was challenging but not too difficult.
14	More time needed for Part A but the rest seemed to run smoothly.
15	I did not know how to calculate the concentration from data collected.
16	I was not too sure about what to write in the interpretations.
17	It was easier to carry out the given procedures but I was not as confident going into the lab as I would have been if I had drawn up my own procedure. I put more thought into the lab if I have to design.
18	The part of the lab (Part A) was not as challenging as Part B because the steps were given. I had a feeling of accomplishment. I liked how the lab progressed.
19	I had trouble with the titration and the calculations.
20	Being given the steps is OK but it also makes you rely too much on the lab manual. It is not your own. The calculations were simple enough although I did not know exactly what to include in the FR. I messed up titrating a few times.

TABLE 73

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB M4

Lab M4: Electrochemical Cells

Student	Written Statements
01	I had trouble organizing myself and I was short of time.
02	Lab not too hard to do, and I was sure I knew what I was doing. My results puzzled me.
03	The sutdent voltmeter did not produce the readings I expected. I was short of time.
04	n/c*
05	I found the lab interesting but there was a high error.
06	A lot of time needed to prepare this lab.
07	The student voltmeter was not very accurate. Interesting lab.
08	n/c
09	Not too difficult to do once I figured out what to do.
10	The reports were not difficult.
11	No difficulty with the reports.
12	The student voltmeters are not accurate, and not enough time to use the VTRM.
13	I was a bit confused with the FR.
14	Everyone should have had the opportunity to use the VTVM.
15	Still not sure about how specific to be in DR, OR. FR OK.
16	Not enough time to repeat any parts of experiment.
17	Interesting lab but difficult and challenging.
18	DR was easy. I knew how to construct the cells, but the FR was the most difficult because explanations had to be found. I found it interesting and challenging.
19	No trouble with any reports.
20	n/c

*n/c means no comments were made

TABLE 74

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB N1

Lab N1: Bronsted - Lowry Reactions

Student	Written Statements
01	n/a*
02	It was interesting to see whether or not my predictions came true, but I found it hard to explain the changes which were not predicted.
03	A very interesting lab and an excellent application of Bronsted-Lowry Theory. Conflicting observations . . . were frustrating and difficult to explain.
04	Most of my predictions turned out . . . but hard to understand some of the conflicting data.
05	n/a*
06	I had difficulty organizing data for my OR.
07	The lab was relatively easy except I misinterpreted one reaction. But I knew what I had done wrong.
08	n/a
09	My predictions were (incorrect). I had trouble with the indicators.
10	A lot of tedious work . . . cleaning all those test tubes . . .
11	I had difficulty explaining why some of my predictions did not work.
12	We were rushed to repeat some of the (tests).
13	n/a
14	Interesting lab.
15	n/a
16	I enjoyed this lab . . . it kept me busy. Predicting acid-base reactions is fairly easy. However, I had a problem explaining why two of the indicators changed when they shouldn't have.
17	It was difficult to organize my data for so many reactions.
18	I felt there were a lot of things to do and I was rather rushed. I found this lab interesting . . . some results were unexpected.
19	Since I didn't know what was going to happen I didn't understand what to do.
20	I had difficulty explaining why two of the experiments did not change like I had predicted.

*n/a means not applicable

TABLE 75

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB N2

Lab N2: Standardization Titration

Student	Written Statements
01	I liked this experiment. It was fairly straight forward yet challenging. Accuracy was important.
02	n/a*
03	This and other labs were challenging. The idea is to get the best possible answer.
04	n/a
05	I think I understood the principle but I suspect my HCl concentration.
06	More time should have been given to teaching proper titration techniques.
07	I'm glad little help was given. It gives us a chance to think.
08	I found it very confusing to try and figure out the concentration of HCl.
09	n/a
10	Getting the results or observations was easy but the application of them in the final report was difficult.
11	It was very easy to overshoot while titrating.
12	Arriving at the end point was difficult.
13	My results for all trials were similar.
14	n/a
15	n/a
16	Very challenging experiment.
17	n/a
18	This experiment was challenging. An excellent illustration of acid-base stoichiometry and polybasic species.
19	This lab was interesting and challenging.
20	This experiment was confusing at first.

*n/a means not applicable

TABLE 76

SUMMARY OF STUDENT WRITTEN COMMENTS FOR LAB N3

Lab N3: Titration - NH_3

Student	Written Statements
01	I had trouble drawing a titration curve.
02	My NH_3 concentration may be totally out because I'm not sure of my HCl concentration.
03	Everything done here depends on what you did the day before.
04	n/a*
05	Difficult lab because the results depend on Lab N2.
06	I don't feel confident about my NH_3 concentration because of all the errors and the value of HCl concentration from Lab N2.
07	n/a
08	I still have trouble understanding titration curves. I really enjoyed this lab. It was the most challenging to date.
09	This lab was too dependent on Lab N2.
10	I did not like the idea of using the concentration of HCl from Lab N2 for this lab.
11	Generally I don't like labs . . . but titrations are much better.
12	I have improved my titration techniques since Lab M3. Mo$^-$ would have been a better indicator. It would be more difficult to overshoot.
13	My NH_3 concentration is unsure because of the HCl concentration. Questions on N52 were okay except for the titration curve. I still have problems with them.
14	I felt I knew what I was doing in this lab. It went well.
15	I liked the experiment but I'm not overly confident about the results.
16	It wasn't easy to arrive at the end point.
17	This lab was straight forward and easy to understand. I like titrations. It is interesting to see how our results will compare (with the teacher's).
18	This lab was not very difficult to perform but the final results are too dependent on results of Lab N2. I was not very confident.
19	I had trouble with the titration curve.
20	n/a

*n/a means not applicable

TABLE 77

Summary of Lab N4 Student Written Comments made on the solicited Question: "How do you like this type of laboratory experiment as a learning experience?"

Lab N4: Common Ion Effect

Student	Written Statements
01	A good way of learning. DR and FR the key; however, handing in the OR was a tense situation at times.
02	I liked it because I had to organize my thoughts and I knew what I was doing before I went into the lab. There is more than one way to perform a lab.
03	Labs need to be done more than once. I like to modify my design but unfortunately we did not have time and noon-hours were not convenient.
04	Absent
05	More time was required by me in doing these labs (than for ALCHEM 10 and 20) but it was worth it. I felt more confident. I liked the freedom given to the student.
06	A very interesting way to approach problems. It seemed more "scientific" and more challenging.
07	I learned a lot from doing it my way. If I made a mistake I had a chance to do it over again. Designing labs was good and I became more aware about exactly what I was doing--maybe actually thinking like a scientist!
08	A good method. Writing DR gives us a better understanding. The OR helps to organize data and see relationships.
09	A good idea to do more of the lab ourselves--we seem to learn more. Difficult at times without some of those hints. I enjoyed Chem 30; was very interesting--more than ALCHEM 10 and 20. For the first time I liked learning chemistry. I had time to think of what I was doing and was able to understand it.
11	It is easier to follow the lab manual but in doing the design you learn considerably more.
12	It is a lot more work than (ALCHEM 10 and 20) but the extra research and time spent preparing make the labs that much more worthwhile. We had to learn from our mistakes. I found the labs enjoyable and challenging especially the titrations.
13	We have to understand the lab before we do it when writing DR. This system should have been started in ALCHEM 10 and 20. A good system.
14	This type of lab is much more challenging (than ALCHEM). Instead of following directions you are made to think about what you are doing. I learn more this way and I found the labs much more interesting. Some of the labs were very long.
15	I liked the program this year because I felt part of the class. In Chem 10 and 20 I just did as I was told but in Chem 30 I felt I was making a good contribution to the class.

TABLE 77 (Cont'd)

Student	Written Statements
16	These labs are a lot better. They force a person to think and are more worthwhile.
17	This type of lab is better than the "work-book" type. These labs are a lot of work however. But they make you think through them before . . . Doing your own DR made things a bit less frustrating. I liked being more on my own in Chem 30, and there were more labs this year.
18	As a learning experience the type of lab we did this year cannot be 'beat'. I learned more about doing labs this year than I did in any other previous course. It took more time preparing, however. I enjoyed the lab set-up very much this year.

TABLE 78

SUMMARY OF UNSOLICITED WRITTEN COMMENTS ON LAB N4

Lab N4: Common Ion Effect

Student	Written Statements
01	I feel the lab program was successful. Interesting.
02	n/a*
03	I like doing labs once (then thinking about it) then modifying design . . .
04	n/c**
05	Unsure of my hypothesis and predictions.
06	More work doing these labs (than ALCHEM 10-20) but has paid off. I feel more confident. Know the material better . . .
07	The interpretations for this lab were the most difficult.
08	I enjoyed this lab except writing the FR.
09	This method of doing labs is good. DR gives a better understanding of the skills needed and the reasons for techniques used. OR and FR (same as DR).
10	It was difficult to predict in this lab.
11	Labs were very interesting although it would have been nice to have a lab which dealt directly with the outdoors and things that affect our lives directly.
12	I hope we will go over (this lab) in class.
13	n/c
14	n/c
15	Writing our own DR meant we had to know what we were going to do--not so last year.
16	I had a better understanding of what was happening in the lab this year.
17	n/c
18	n/c
19	The common ion effect was not covered in class--more informaton was needed.
20	n/c

*n/a means not applicable

**n/c means no comment

APPENDIX N

TEACHER'S LOG

TABLE 79

Teacher's Log - Lab L1

Date	Field Notes
2/25/82	After going over the rules of safety on page 3 of the laboratory manual (Revised ALCHEM 30 Laboratory Investigations) students spent the rest of the period equipping the lab boxes. Students were looking forward to the year's lab work.
3/ 5/82	Lab L1 Students asked many questions in spite of being told not to ask questions during labs unless materials were needed or an emergency arose. Getting in the DR's before the lab work session started was difficult and many students had not prepared the OR. During the experiment there were few problems with the neutralization. Some worried about the end-point since no indicators were provided. Bb$^-$, Mo$^-$, HPh, and litmus were issued. Some indicators showed the acid solution to be slightly more concentrated than the base. Some measured the difference and wanted to know what effect the difference would have. It was their problem to solve they were told. The post lab discussions were mostly about problems and errors in the reports. The majority failed to express their design in quantitative terms; and many errors about formats, cover pages, significant figures and other reporting techniques were made. In the OR the errors were: failure to record only that which was measured, failure to record all data, confusing observations with conclusions and inferences. In the FR the errors were; calculating molar heat; distinguishing between H and ΔH and also between the heat of reaction and molar heat of neutralization. The interpretations in the FR were weak. Marking the lab reports was onerous. General Impressions. During the laboratory session many students seemed lost and asked a lot of questions. Problems with equipment, procedures, and general techniques were the main reasons for the difficulties, and it was apparent that students were not solving their own problems but expected the teacher to do so every time a problem arose. Upon being told to solve their own problems many expressed surprise but went about the task willingly. The enthusiasm generated during this first lab was undoubtedly due to the novelty of being in the laboratory. It would remain to be seen if the teacher or nature of the experiment were contributing factors.

TABLE 80

Teacher's Log - Lab L2

Date	Field Notes
3/11/82	Lab L2 Although students had been told there would be sufficient time to complete the experiment many students came early during the noon-hour to assemble apparatus, cut and bend the necessary glass. During the lab period designs were being changed almost after every trial. The pinch clamp shown on page 6 was a source of concern for many students. (See Lab Manual). Many students experienced failures in attempting to measure the molar heat of vaporization, but many of the process skills seldom mentioned or experienced in a high school chemistry laboratory were seen in this lab. The enthusiasm was high for this class as it had been for the last pilot class. The enthusiasm was due to the challenge offered by the experiment, for Lab L2 was, for many students, a real challenge. Several students asked to work at noon and after school in order to redo the experiment. General Impressions. While this experiment was being field-tested during the pilots it became apparent that students would be required to work in pairs in order to accomplish all the necessary tasks. Although this mode had not been contemplated for any of the experiments of this study (Lab L2 is the only exception), it was clear during the experiment that students should be given the opportunity, at least occasionally, to work with others. Working cooperatively to solve problems is an accepted and necessary activity in science; and the pleasure students derive while sharing tasks, failures and successes is important and is also a practical way to experience the "processes" of science. While in grade X and XI students have generally worked in pairs because of class size, it appeared that students still preferred to work in paris.

TABLE 81

Teacher's Log - Lab L3

Date	Field Notes

3/19/82 Lab L3

During the prelab discussions, students still asked questions regarding "how much." The task of having to determine the design in quantitative terms was still a problem.

The class had some trouble performing the experiment: a few students tried to weigh ice on a paper towel and in other ways. For some students the laboratory period was a learning experience. One student said, "In my original design I wanted to measure a specific amount of ice but I realized later while performing the lab that it was easier to just add any amount of ice, then weigh the ice later after it had melted."

Since students appeared to be having trouble with this experiment, I circulated around the lab and asked several the question: "Do you not think it would be a better experiment if you were told how to perform each step, i.e., be given the design?

"No, this way is more interesting . . . I have a say in what's going on."

"Well, maybe . . . but I like this system."

"It would be easier . . . this is OK."

"No . . . because I want to go to university and I believe that's how you have to work there."

"Yes, I guess so but I like it this way and I would not like to go back to the old way."

"Yes, I would . . . I often feel lost before the lab."

General Impressions. The first two lab reports required an inordinate number of corrections and reminders. Students needed a lot of help to write the reports. However, for this lab there was a decided improvement in the writing, and fewer corrections were necessary. In spite of being given less structuring, students were already learning some important skills in communications by means of the lab reports. Upon asking some students how they enjoyed working on their own rather than in pairs, the majority still favored working in pairs.

At this stage of the academic year, the students' attitudes toward science seemed to be directly proportional to the level of the teacher's expectations. Unless the teacher stressed specific attitudes (Appendix E), few were exhibited.

TABLE 82

Teacher's Log - M1

Date	Field Notes
3/26/82	Lab M1

During the prelab a lot of questions were asked about how to tabulate data. Students seemed at a loss to be able to organize their data. Many brought up plans before the lab period began and asked for approval. Although the class was doing the work correctly many students were still not very confident about the design part of the lab.

There were two purposes in Lab M1. The first required that students try to find, by experiment, which reactions were spontaneous. The second required that students try to find the relative tendencies of substances to react with each other--a more difficult task. Only half of the class realized the significance of this second purpose. After the FR were returned and during the post-lab discussion many students complained that the purpose had not been properly emphasized before the lab and during the prelab sessions. Others said that the lab manual had not been explicit on this second purpose. The experiment was a good lesson in organizing data "in order to identify regularities." (Appendix B) The class discussion involved many students.

General Impressions. In order to have students produce work at a higher level of inquiry students must be placed in challenging situations. The setting that will produce quality work has to be created first. Asking students to come up with a scheme as sophisticated as the one required in Lab M1 and M2 would have been fruitless unless the students had been placed in the laboratory situation which challenged them.

TABLE 83

Teacher's Log - Lab M2

Date	Field Notes
4/15/82	Lab M2 This experiment had undergone considerable modification during the pilot and some apprehension existed about how students would be able to cope with it. The color tests which were demonstrated before the lab were to enable students to distinguish each of the species labelled A, B, C and X, Y, Z. See Appendix E, Revised ALCHEM 30 Laboratory Investigation, page M2. Students seemed rather confused and some said they were not sure how to determine if a chemical change took place. The problem of classifying the oxidizing and reducing agents was clear enough but some seemed confused about how they were going to be able to find this out. After the lab period many students expressed that they enjoyed the challenge but they had been very apprehensive about the mysterious reagents before the lab period began. General Impressions. Lab M2 had in addition to the setting and challenge of Lab M1 the added interest of the unknown reagents. This experiment, which had caused considerable anxiety before the labwork started, turned out to be one of the more enjoyable ones for the class. For the student, laboratory work will probably always be considered more interesting than classroom seat work, regardless of the nature of the activity; but surely some experiments ought to go beyond the ordinary and definitely challenge the student. Students were producing better quality work on the reports in this lab, and the class had apparently adjusted to working singly.

TABLE 84

Teacher's Log - Lab M3

Date	Field Notes
4/23/82	Lab M3 One of the lessons learned from the pilot study showed that not only are the process skills learned in the lab but some of the skills are best taught by training students. During the pilot program it was found that students were unable to complete Part A and Part B in the 80 minute period available. On the second day instead of completing Part B the class was asked to redo the entire lab. The skills learned on the first day should enable them to complete the entire lab on the seond day. In addition to the training which took place, the required skills were probably learned because they were necessary and made relevant by the necessity of the task at hand. Few students complained about the time problem after the laboratory period although many students mentioned in the written comments that they were rushed during the experiment. General Impressions. Students of the pilot and main study always enjoyed titrating. The question is why. Getting to use various types of apparatus, engaging in multi-step operations, and not knowing the concentrations of the solutions all contributed to student interest. But there is more. Students of both pilot and main study had been challenged to compete with each other to find the concentration of the solutions known only to the teacher. They were told their values would be compared to the class average and to the teacher's. Indeed, students were externally motivated in this experiment and they enjoyed it.

TABLE 85

Teacher's Log - M4

Date	Field Notes
3/29/82	Lab M4 Students found the experiment interesting and many went about their tasks with a passion; however, the biggest disappointment came while processing data. The relatively large percent errors obtained were due to the student voltmeter. The vacuum tube voltmeter (VTVM) gave a much better reading but not all students were able to use the meter since only two were available. Students were genuinely concerned about their results although the class (mean) error was only 11%. For the pilot study, prior to some refinements, the class error had been 30%. In attempting to get better results, a number of students, having calculated the expected emf, tried several modifications. Most of the modifications were of the trial and error type. General Impressions. This experiment has considerable potential as an interesting and worthwhile acitivity. Replacing student meters with high resistance meters, making available more precise concentrations for the solutions, and providing additional materials (solutions and metals) should enable students to obtain greater precision. Students had come to the realization that their data is easier to interpret if it is obtained with precision. This possibly explains why students are very meticulous in making measurements, and finding them very disappointed if results have a high percent error is not surprising. In order to foster a respect for evidence, students must be able to collect data which are bona fide in at least a few experiments.

TABLE 86

Teacher's Log - Lab N1

Date	Field Notes
5/ 4/82	Lab N1

In this lab students were required to determine the products of 28 reactions (a) by predicting the products by the Bronsted-Lowry Theory and (b) by experiment. In the interpretation (FR) students were to compare predictions with observations then list and discuss any conflicting observations. Students found this experiment very interesting although it was difficult to see why at first. The experiment was undoubtedly a good one but did not appear as interesting as many students made it out to be.

During the prelab discussions students had been told they would find anomalies in their observations. They were not told which ones but they were told they had first to find the anomalies, then find an explanation for them. Furthermore, students were told, the explanations would not be found in the ALCHEM materials. The students would have to come up with their own theories. "There are no wrong answers. If your explanations are reasonable you will get credit."

The experiment offered an unusual opportunity to exercise the process skill of interpreting data.

General Impressions. The majority of the class was very serious about discovering the anomalies. Some students repeated parts of the experiment at noon-hour, others after school. Most of the operations for this lab were repetitious and it was thought that extra measures might be required to avoid monotony. Although student attention and interest had not been a problem during the pilot, the main study students had considerably more reactions to investigate. In spite of the repetitious nature of the experiment, student interest remained high. Discovering the anomalies and explaining the color changes, the consequential aims of the experiment were important to students. Furthermore, these incentives were not only responsible for promoting interests but were primarily responsible for developing inquiry skill.

It was during this experiment that a particular student activity was observed which had not been considered important until now. The amount of pupil-pupil interaction during the laboratory period was very active. But what made this activity unusual was that it had been occurring throughout the year--during every laboratory class. They were sharing observations, discoveries and disappointments with each other. With more conventional experiments--those with less inquiry--students are not involved with their work to the same extent and they do not display the same interest and enthusiasm.

TABLE 87

Teacher's Log - Lab N2

Date	Field Notes
5/10/82	Lab N2 No prelab or post-lab discussions were held for this lab. They were not necessary. General Impressions. In this lab which required a titration, the same interest was displayed by students as had been done for Lab M3, the redox titration. Again, students were challenged to find the HCl concentration. They were told that the concentration of the HCl would be revealed only after the post lab discussions. The previous labs which required a determination were marked without penalty if the experimental value was less than 20% of the expected value. For labs Lab N2 and N3 the student was penalized if deviations exceeded the accepted value by more than 7%. These penalties were seen by students as incentives.

TABLE 88

Teacher's Log - Lab N3

Date	Field Notes
5/11/82	Lab N3 Students seemed to know what they were doing in this lab and the teacher had little to do other than walk around and ask discerning questions to see if students knew what they were about. The concentration of NH_3 had been determined quite accurately to three significant figures, and each member of the class was competing to see who would get the best determination. The accepted value would be revealed only after the reports were completed. General Impressions. Some students expressed concern that their value for NH_3 depended very much on the value obtained for HCl from lab N2. Unfortunately students were not told at the time of the experiment that Lab N3 would be graded solely on the results of data collected in Lab N3. These concerns apparently had little effect on the class percent error since Lab N3 produced the smallest percent error of the year (See Table 55). This was the fourth time students had performed titration experiments and, not too surprisingly, their success in performing the necessary manipulative skills was evident. In addition student attitudes towards learning showed maturity not only during the performance of the experiment but later in the quality of the laboratory reports.

TABLE 89

Teacher's Log - Lab N4

Date	Field Notes
5/16/82	Lab N4 The process skills in An Inventory of Processes in Scientific Inquiry (Appendix B) were reviewed during the prelab sessions. On lab day before proceeding to the work bench students were required to complete the DR as was customary. However, for this lab the design report required students to predict what would happen regarding the phenomenon stated in the Purpose. In addition, the DR had to include a hypothesis for the phenomenon followed by the customary experimental steps. General Impressions. The skills of communication required in Lab N4 were not more difficult than those which had been required during the year but there were more of them and they were varied. The level of achievement in the processes of science was evident, and students scored reasonably well on the DR and OR; however, in the FR not everyone was capable of interpreting the data satisfactorily. Interpretations by means of Le Chatelier's Principle were used by a few students, but not too many students thought to use equilibrium or kinetics (reaction rates). Nevertheless, the experiment provided the opportunity for many process skills at a high level of scientific inquiry. This relatively simple experiment provided students with a problem to identify, a prediction to formulate, a hypothesis to find, data to collect, and an interpretation to fit the facts.

APPENDIX O

STUDENT RAW SCORES ON FORMAL INSTRUMENTS

TABLE 90

MAIN STUDY - STUDENT RAW SCORES ON FORMAL INSTRUMENTS

ID	DIQ	CH 30 TOSA	PRE TOSA	POST TOSA	PRE PROCESS	POST PROCESS	LAB REPORTS			LAB MARK %	FINAL GRADE
							DR	OR	FR		
01	109	42	21	28	31	33	3.7	3.4	6.7	69	65
02	110	35	26	24	34	32	4.4	4.3	7.5	81	64
03	122	47	19	23	36	36	4.1	4.3	9.0	87	67
04	113	40	22	23	26	33	4.2	4.1	7.8	81	69
05	130	55	33	32	38	38	4.6	4.4	9.6	93	91
06	119	49	22	25	34	33	3.7	4.0	7.7	77	71
07	105	37	24	21	28	27	2.6	3.2	6.8	63	58
08	106	46	19	26	28	30	4.0	3.4	7.2	74	72
09	101	39	21	20	20	30	2.7	2.9	4.7	52	52
10	122	48	28	29	36	36	4.3	3.5	6.7	72	66
11	118	47	24	25	28	31	3.3	4.4	5.7	67	83
12	103	47	24	25	26	26	4.0	4.2	7.3	77	66
13	111	33	25	24	32	32	4.0	3.8	7.9	78	60
14	120	48	28	26	31	32	3.5	3.8	5.7	65	82
15	126	43	25	29	37	36	4.3	4.5	9.0	89	68
16	116	48	19	23	31	35	4.2	4.5	8.1	84	78
17	122	51	26	26	37	39	4.5	4.8	9.0	92	82
18	115	47	24	24	33	32	4.1	4.5	7.2	79	72
19	129	35	27	28	33	33	3.3	3.6	6.6	67	61
20	107	35	24	21	29	33	4.1	4.4	8.0	82	68
$\overline{X}$	115.2	43.6	24.05	25.10	31.40	32.85	3.9	4.0	7.4	76	70
S	8.4	6.1	3.4	2.9	4.4	3.2	0.6	0.5	1.2	10	10